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Trailer Mounted Water Recovery and Reuse System

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
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Trailer Mounted Water Recovery and Reuse System
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SHIPYARD WASTEWATER RECOVERY AND REUSE GUIDANCE MANUAL

Technical Report

NOVEMBER 30, 2000

BY:

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ABSTRACT

Concurrent Technologies Corporation (*CTC*) was tasked by the National Shipbuilding Research Program to conduct the *Trailer Mounted Water Recovery and Reuse System Project*. This project, which was necessitated by the increasing wastewater discharge regulations that are affecting the shipbuilding industry, was devised to assist in decreasing the total water discharge by demonstrating various wastewater recovery and reuse technologies. As part of this project, *CTC* developed the *Shipyard Wastewater Discharge Survey* to identify and collect the information on shipyard wastewater discharges. Using this data, recovery and reuse technologies were selected and demonstrated on five waste streams at three participating shipyards. Based upon the results from these demonstrations and other prior testing, the project team compiled this *Shipyard Wastewater Recovery and Reuse Guidance Manual.*

The Guidance Manual includes:

a) Guidance on conducting a baseline evaluation of current shipyard or repair facility process waters, including information gathered during the project using the *Shipyard Wastewater Discharge Survey*.
b) Information and data on the results of the individual on-site (shipyard) water recovery and reuse demonstrations including the operation and maintenance of the demonstration equipment.
c) Analysis of anticipated cost savings and lessons learned from each technology demonstration; a summary of these results are shown in Table 1 below.
d) A summary of the capabilities of recovery and reuse technologies: reverse osmosis, microfiltration, ultrafiltration, diffusion dialysis, membrane electrolysis, ion exchange, and vacuum evaporation.
e) Developed selection criteria to assist a facility in matching potential technologies with their wastewater streams.
f) Associated regulatory compliance issues.

Table 1. Demonstration Results

	Solution	Location	Technology	Cost/Benefit[A]
1	Pipe Bending – alkaline cleaner	Bath Iron Works	Ion Exchange (3 types)	NPV = $600
3	Compressor Flush	Avondale	Microfilter	NPV = ($700)
4	Pipe Flush	Avondale	Microfilter	NPV = $1,200,000
5	Steam Cleaning	NASSCO	Microfilter	NPV = $367,500

A Net present value calculations based on fifteen years.

Numbers shown in parenthesis are negative.

In total, the information in this manual should assist shipyards in determining the feasibility of recovering and reusing facility wastewater discharges.

LIST OF TERMS AND ACRONYMS

Analytical Terms:

Ag .... Silver
BDL .... Below Detection Limit
BOD .... Biochemical Oxygen Demand
COD .... Chemical Oxygen Demand
Cl^- .... Chloride ion
Cr .... Chromium
Cu .... Copper
DI .... Deionized
DO .... Dissolved Oxygen
GAC .... Granular Activated Carbon
H^+ .... Hydrogen proton (acid)
HCl .... Hydrochloric acid
Hg .... Mercury
HPLC .... High Performance Liquid Chromatography
MEK .... Methyl Ethyl Ketone
N/A .... Not Applicable
P .... Total Phosphorous
Pb .... Lead
SAC .... Strong Acid Cation
SBA .... Strong Base Anion
TDS .... Total Dissolved Solids
TSS .... Total Suspended Solids
WAC .... Weak Acid Cation
WBA .... Weak Base Anion
Zn .... Zinc

Units:

A .... Amperes
°C .... Degrees Centigrade
cfm .... Cubic Feet per Minute
°F .... Degrees Fahrenheit
gph .... Gallons per Hour
gpm .... Gallons per Minute
h .... hours
kW .... Kilowatt
L .... Liters
mg .... milligrams
mg/L .... milligrams per liter = parts per million
mm .... millimeters
mS .... milli-Seimens
ppb .... parts per billion
psi .... pounds per square inch
ug (or _g)........ micrograms
VAC .... Volts Alternating Current

Miscellaneous Acronyms:

ASTM .... American Society for Testing and Materials
Avondale .... Avondale Shipyards Division
BIW .... Bath Iron Works
CCP .... Commercial Chemical Products
CRF .... Code of Federal Regulations
CTC .... Concurrent Technologies Corporation
CWA .... Clean Water Act
EPA .... Environmental Protection Agency
ETF .... Environmental Technology Facility
HW .... Hazardous Waste
LQ .... Large Quantity
NASSCO .... National Steel and Shipbuilding Company
NDCEE .... National Defense Center for Environmental Excellence
NPDES .... National Pollution Discharge Elimination System
NSRP .... National Shipbuilding Research Program
MP&M .... Metal Products and Machinery
POTW .... Publicly Owned Treatment Works
QA/QC .... Quality Assurance/Quality Control
RCRA .... Resource Conservation and Recovery Act
SIC .... Standard Industrial Classification
SW .... Surface Water discharge
TSD .... Treatment, Storage and Disposal
WWTF .... Wastewater Treatment Facility

1.0 INTRODUCTION

This guidance is an outcome of the National Shipbuilding Research Program (NSRP) Project N1-96-5, *Trailer Mounted Water Recovery and Reuse System Project*. The impetus for this project was the increasing attention being paid to the adherence to wastewater discharge limits, specifically discharges to surface waters. Since a majority of the shipbuilding industry is located on or near major waterways, surface water discharge requirements greatly affect the shipbuilding industry. A variety of laws and regulations have been created on the state and local levels to protect surrounding waterways, wetlands, waterfowl, and watershed protection. Because of this, in most cases, the water quality of the discharge stream must be greater than that of the surrounding water. Increased regulation also brings increased monitoring of wastewater discharges. To reduce the effects of these rules and regulations, it is in the best interest of the shipbuilding industry to identify methods of reducing wastewater discharges.

In addition to increased scrutiny of existing wastewater discharge regulations, additional regulations affecting the shipbuilding/maintenance industry are in the works. These include the expansion of the Federal Water Pollution Control Act (commonly referred to as the Clean Water Act - CWA) and similar state laws. Also included are the effluent guidelines and pretreatment standards for new and existing facilities that manufacture, maintain, or rebuild finished metal products that are being currently developed by the U.S. EPA (the Metal Products and Machinery source category). In addition, it is becoming more difficult to obtain exemptions for increased discharge limits or modifications to a present National Pollutant Discharge Elimination System (NPDES) permit. This could hinder shipyard output, increase production costs, delay product delivery, or force a shipyard to set specific workload limits.

To meet this objective of reducing wastewater discharges, this project investigated the feasibility of decreasing these discharges at the source through recovery/reuse technologies. Most of these technologies investigated are proven, cost effective, and have been easily implemented within other industries. Trailer-mounted units were used for this project because of the ease and flexibility that they allow enabling them to be moved to the point of generation for recycling of the wastewater stream. However, the information in this manual applies to stationary equipment also.

Water recovery and reuse systems have been demonstrated as economical pollution prevention technologies that decrease process wastewater discharges. The recovery and reuse systems investigated for this project were the following: reverse osmosis, microfiltration, ultrafiltration, diffusion dialysis, membrane electrolysis, ion exchange, and vacuum evaporation. The demonstration portion of this project determined the efficiencies and capabilities of these equipment in removing / reducing common contaminants in wastewater streams.

2.0 SCOPE AND USE OF THE GUIDANCE

This guidance is intended to assist shipyards in decreasing the total wastewater discharge of their facilities. The impetus for this project was the need to assist shipyards in being proactive in addressing the increasing wastewater discharge regulations that are affecting the shipbuilding industry. It is the objective of this guidance to assist shipyards in identifying potential wastewater streams for recycling and to become more knowledgeable of current technologies that are available for process water recovery and recycle in shipbuilding and repair yards. Furthermore, this guidance will assist the shipyard in determining the feasibility of implementing the technologies at their facilities.

The Guidance Manual includes:

g) Guidance on conducting a baseline evaluation of current shipyard or repair facility process waters, including information gathered during the project using the *Shipyard Wastewater Discharge Survey*.
h) Information and data on the results of the individual on-site (shipyard) water recovery and reuse demonstrations including the operation and maintenance of the demonstration equipment.
i) Analysis of anticipated cost savings and lessons learned from each technology demonstration.
j) A summary of the capabilities of recovery and reuse technologies: reverse osmosis, microfiltration, ultrafiltration, diffusion dialysis, membrane electrolysis, ion exchange, and vacuum evaporation.
k) Developed selection criteria to assist a facility in matching potential technologies with their wastewater streams.
l) Associated regulatory compliance issues.

Through use of this manual, shipbuilding and repair yards will become more knowledgeable of current technologies that are available for water recovery and reuse in process areas at their facilities.

Shipbuilding and repair facilities, which use this guidance, should be expected to achieve economic, compliance, and operational advantages.

3.0 PROJECT BACKGROUND

Concurrent Technologies Corporation (*CTC)* was tasked by the National Shipbuilding Research Program (NSRP) to conduct NSRP Project N1-96-5, *Trailer Mounted Water Recovery and Reuse System Project*. The objective of this project was to demonstrate various water recovery and reuse technologies in shipyard applications to decrease the total water discharged from the shipyard. Three shipyards participated in this study: Avondale Shipyards Division (Avondale), Bath Iron Works (BIW), and National Steel and Shipbuilding Company (NASSCO). Facility information for these shipyards is located in Appendix A.

In the completion of this project, several tasks were conducted. The first task, *Shipyard Wastewater Discharge Survey*, identified current wastewater streams generated by shipyard processes. The second task, *Demonstration of Wastewater Recovery and Reuse Technologies*, involved prioritizing these waste streams and demonstrating recovery technologies at the shipyards on these wastewater streams. And finally during the third task*, Development of Shipyard Wastewater Recovery and Reuse Guidance Manual*, all the information collected during this project was summarized for use by shipbuilding and repair yards to assist them in prioritizing wastewater streams for recovery and reuse and selecting the appropriate recovery technologies.

During the first task, *CTC* and the three shipyard operations prepared a *Shipyard Wastewater Discharge Survey* for their use (reference Appendix B). This survey was patterned from the U.S. Environmental Protection Agency's (EPA's) 1996 Metal Products and Machinery (MP&M) Industry Phase II Survey. *CTC* visited each of the three shipyards to assist them in quantifying facility wastewater discharges, following the prepared survey. *CTC* compiled and analyzed the information from each survey and organized that information into the *Shipyard Wastewater Discharge Survey Report*.

Based on the results of the *Shipyard Wastewater Discharge Survey*, *CTC*, in conjunction with the three participating shipyards, selected process areas at each participating shipyard to demonstrate various water recovery and reuse technologies.

CTC demonstrated and evaluated various wastewater treatment technologies at each of the three participating shipyards. *CTC* facilitated and coordinated the on-site demonstration, evaluation, and monitoring of various water recovery and reuse technologies using trailer-mounted, mobile wastewater treatment systems. The participating shipyards provided hookup and maintenance of the units. The shipyards also addressed any local regulations as necessary for the water recovery and reuse technology demonstration and evaluation.

CTC collected, analyzed, organized, and evaluated the data from the demonstrations for point-source reduction potential. In addition, *CTC* prepared a cost benefit analysis for several of the demonstrated technologies. The lessons learned from each demonstration effort as well as any applicable regulatory issues encountered from this effort were organized and reported by *CTC* into this Guidance Manual for shipbuilding and repair yards.

This Guidance Manual is a tool for public and private shipbuilding and repair yards to identify water sources available for recovery and reuse. The Guidance Manual also identifies and describes various technologies available for recovery and reuse of water in shipbuilding and repair yard operations.

Through this project, shipbuilding and repair yards became more knowledgeable of current technologies that are available for water recovery and reuse in process areas at their facilities.

4.0 IDENTIFYING WATER SOURCES FOR RECOVERY AND REUSE

In the past, compliance drove shipyards to treat the wastewater for its disposal rather than for its recovery and reuse. Therefore, designs for existing wastewater treatment systems may need to be modified, particularly with respect to segregation of the water at the shipyard. However, segregation costs money requiring satisfactory payback. This section describes an approach to identifying water sources for recovery and reuse. By following this approach, a shipyard may effectively treat the wastewater and also implement water reuse programs on a cost-conscience, larger scale.

4.1 Conducting an in-house wastewater survey

In order to identify wastewater streams for recovery and reuse, a thorough understanding is needed of all wastewater streams generated in a facility. It is recommended that an in-house survey of these wastewater steams be conducted. This survey data is needed to baseline the quantity and types of contaminants in the wastewater. The *Shipyard Wastewater Discharge Survey* (Appendix B) developed for this project is useful to ensure that this data collection effort is complete. The data collector should search company records such as materials procurement and usage records, parts production records, reporting requirements for the local, state, and federal regulatory agencies and their Publicly-Owned Treatment Works (POTW); storm water analysis data; and on site Wastewater Treatment Facility (WWTF) records. However, the data collector needs to balance the value of the data against the time that would be required to obtain the data.

To find the optimum solution for a shipyard, identify the source or sources of the greatest cost and the individual contributors to the cost. In an older facility that has undergone numerous expansions and revisions, an in-house survey can be complex. Typically, data from the top 20% volume sources of industrial wastewater, and also the top 20% of contaminated industrial wastewater, will have the greatest impact. Most often, a shipyard will find the source of greatest cost is the source of most problems. Other times, findings will point to a simple, isolated process causing the majority of problems. Typically, it is important to obtain qualified technical assistance in engineering, chemistry and wastewater treatment to help with this process. Innovation and experience are essential to make the right decisions.

With the selected water sources, approach the survey in steps:

1. Understand the characteristics of the wastewater and the product water.
2. Review the current mechanical infrastructure for collecting and redistributing the water.
3. Monitor key operational variables impacting water supply and quality.
4. Frequently review all water costs.

Further information on these survey steps is given below.

4.1.1 Understand the Water and its Use

Understanding the characteristics of the wastewater and the product water is the first step to treat or reuse the water. Beyond chemical composition listed in the written product literature, the shipyard should sample the top 20% industrial wastewater sources and analyze them for various contaminants. In general, these waste streams will have the greatest potential to be recycled or reused elsewhere within the shipyard. This analysis will provide the information needed to initiate a wastewater reuse program. Analyzing only the highest probability candidates (the top 20%) enables efficient use of funds, eliminating analysis costs for wastewater streams that have a low probability of reuse.

The characteristics to measure are the following:

- Design daily flow rate (average and peak),
- Temperature of the wastewater,
- pH of the wastewater,
- Influent COD, BOD, TSS, and Oil and Grease concentrations (average and peak),
- Influent nitrogen and phosphorous and anion concentrations,
- Influent TDS concentration along with complete metals scan.

Again, review the MSDS sheets and materials receiving/ordering records (e.g., “hard-cards”) for any and all chemicals used within the shipyard to avoid potential incompatibility with the recovery and reuse implementation. Once this data is obtained, options for reuse can be determined.

Study the manufacturing process to reveal what type of water it requires. Establish the criteria of the water's quality for acceptance either for recycling back to the generating source, or for reuse elsewhere within the shipyard. This will identify what modifications to the existing installation are necessary, and what potential impacts to equipment or process one should expect.

Later, additional chemical analyses of the influent may be required, to ensure that the treatment process would perform efficiently. For example, manufacturers of reverse osmosis systems typically require a measurement called the Silt Density Index (SDI) to ensure that the membrane does not foul prematurely. Also, during bench- and pilot-scale testing, chemical analyses are performed on select unit operations. These analytical laboratory activities (see section 4.1.3) should be incorporated into the written project and technical plans.

The following is an example of operational problems encountered due to **not** pilot testing. The industrial wastewater treatment facility built for the City of Chandler, Arizona experienced trouble on start-up because it did not anticipate the actual composition of wastewater to be treated. The industrial wastewater came from the electronics industry it supported. The wastewater concentrations were higher than anticipated in inorganics, silt density index, turbidity, and microbial activity. The resolution to this trouble was to derate the reverse osmosis equipment (relax recovery requirements, clean more frequently, pump faster, etc.) while installing an ultrafiltration system to pretreat the reverse osmosis feed.

4.1.2 Review Shipyard Infrastructure

Another option for review, besides closed-loop water reuse, are cases where a wastewater from one process may be cleaned partially and then used as feed water to another, more forgiving, process primarily industrial utilities. The factors to consider are worker health, flow demands, heating or cooling requirements, emissions control, final effluent treatment and regulatory restriction. This application has saved individual industrial operations millions of dollars annually due to the savings in water and its overall treatment requirements.

Fresh water flowrates can be reduced to a minimum by taking into account all the industrial processes simultaneously and favoring water reuse over introducing more freshwater at each process step. Wastewater from one process step can be reused directly in another process, as long as any of the contamination concentrations do not interfere with the receiving process. Prefer the reuse of water within the same processing operation. When a contaminant limits the reuse of the wastewater, consider treating the water to remove that contaminant so that the remainder of the water can be reused directly or blended with another treated water source to permit its reuse.

However, modifying the existing water distribution and treatment system for water conservation projects are often relatively costly. Piping changes, while often saving water, actually can increase overall costs if not planned carefully with the whole system in mind. Obtain shipyard-piping drawings and physically trace the piping of the selected water sources. Conflicts with the existing piping and shipyard operations layout may impact optimal controls.

Determine the ease of segregating the wastewater from other sources of contamination. Especially watch out for blending organics (e.g., soaps, detergents, organic solvents, petroleum and grease) with inorganics (e.g., metals, mineral salts, and mineral acids). There is no single separation process that will economically remove both organic and inorganic contaminants from wastewater. There are several ways of collecting the spent rinse water for reuse. Many installations co-mingle the rinse waters through a single pipe, while other installations segregate rinse waters (sometimes due to chemical compatibility constraints).

Building a new wastewater treatment facility provides an opportunity to include the water reuse distribution and treatment system in the design. Space planning for water treatment equipment and strategy planning for redundancy and monitoring requirements of the recovery process are also important during the design of the water recovery system. During process reviews, consider whether a process change will reduce regulatory liability and future risks. The relaxation of wastewater distribution requirements contributes significantly to this objective.

4.1.3 Monitor Key Operational Variables

Water reuse will involve more people to evaluate the impacts of recycling the spent rinse-water back to the manufacturing process. Facilities engineers and chemists will need to understand the variables in the recycled water and be able to produce industrial shipyard water with consistency. Requirements on analytical capability and the flexibility in responding to excursions need to be considered. Process engineers and quality control will need to qualify the use of the recycled water back to the manufacturing process as well.

Sampling and Operation Impact

With the wastewater isolated, monitor the technical and operational factors for water reuse. Monitor the quality of the water targeted for reuse for an extended period of time in order to increase the confidence level on controlling and monitoring the quality of the spent rinse water. The water should be checked that it satisfies regulatory pretreatment standards prior to reuse outside of its operation, such as for wet scrubbers or cooling towers. Regardless of whether the scrubbers use city water or spent rinse water for make-up water, they will need to be maintained and operated in the same manner.

The shipyard's paramount criterion for acceptance is worker health and safety. The process needs to integrate into the shipyard operation so that it can be safely operated. The shipyards are very familiar with Job Safety Analyses, and the Occupational Safety and Health Administration (OSHA) regulations pertaining to risk and hazard analyses.

Bench and Pilot Testing

To determine non-standard and unknown process parameters, perform treatability studies at the bench-scale to obtain that data. Treatability studies determine the effectiveness of continuous system operation, and its performance in terms of contaminant rejection and volume of water recovery. For example, it measures the frequency of membrane cleaning, and establishes unknown operating and design parameters for full-scale systems. Test only those parts of the process where data is unknown – the entire process need not be duplicated for bench tests. Similarly, conduct pilot tests where necessary to collect unknown process data. If a process is being scaled from a smaller operation, it is prudent to scale up to no more than ten-fold. For example, if the process data obtained on the bench is for a process that will be operated at one hundred times the flow, then test for the same process parameters on the pilot-scale (at ten times the bench-scale flows).

For a new application, one of the most important selection criteria is to subject bench- and pilot-scale systems with the actual wastewater. Quantify the system when it is exposed to the anticipated range (variability) of wastewater characteristics to measure:

- Pretreatment requirements,

- Percent recovery of the desirable constituents and percent rejection of the undesirable constituents (typically high for reuse and zero discharge systems),
- Cleaning procedure requirements (chemicals, frequency and duration),
- Disposal of the concentrate (if it cannot be reclaimed, post-treatment can be estimated), and
- Plant operational requirements can be quantified, with the preferred level of automation for the system.

For separation processes, collect samples of the feed solution, purified water, and concentrate, (all three are necessary in order to assess for system accumulation or change of constituents). The analyses will confirm process chemistry and whether the purified water (or, in some cases, the concentrate) can be reused in the process. It is important to note that pilot testing is not always required, but rather depends on the experience of the system on similar applications.

Following that set of testing, focus on design parameters such as pressure, flow rate, temperature and pH. Evaluate how much waste is generated by the recovery process, and whether this is economically satisfactory (e.g., is the volume of the waste about the same; is it more easily treatable; can the concentrated stream be found to have value/reuse). Consider how much labor and energy must be expended to recover the water resource.

Example – Evaluating the Recovery and Reuse of Aqueous Degreasers

First, review the constituents of aqueous degreasers and their properties with suppliers and their product literature. The general constituents of aqueous degreasers include the following:

- Alkaline salts such as sodium or potassium hydroxide, neutralize acidic soils/contaminants. Alternatively, acid salts such as sodium phosphates could exhibit detergency, especially in the case of mineral oil and also bind ions that cause hardness.
- Co-solvents lower the surface tension of the cleaner, promote solubility of surfactants, and stabilize oil emulsions.
- Sequestering or chelating agents bind problematic ions such as calcium or iron, which tend to form deposits on cleaned parts.
- Wetting/emulsifying agents (surfactants) help remove oil from dirty parts and stabilize the removed oil, preventing it from redepositing on the degreased part.

Next discuss the process with shipyard operations personnel. Review the degreasing chemical solution used, the degreasing equipment process (e.g., immersion wash, spray wash, ultrasonic, heat), and how the degreasing process is controlled. This determines the final cleaning quality. With use, the degreasing chemicals begin to show signs of degradation from accumulation of the contaminants such as oil and grease (O&G), metals and particulates. Oil skimmers and bag filters should be used to remove free oils and particulates. However, the degreasing solution continues to show degradation due to a variety of causes:

- The alkaline salts will become neutralized;
- The metal-loading can overcome the sequestering agents' capacity to keep the metals in solution; and
- Oil and grease, if held in the emulsified form, will consume the surfactants to a point where emulsification action is compromised.

Finally, list options to correct these limitations. For example, micro/ultrafiltration (bench/pilot tested) can be tested and optimized for flow rates, fluid temperature, inlet pressure, trans-membrane pressure, back-pulse duration, back-pulse frequency, and material of construction. With success, the micro/ultrafiltration removes colloidal contaminants and the chemistry can be corrected by adding sufficient depleted components. But as dissolved salt contaminants continue to build, the chemical degreasing solution will no longer prevent redeposits of the contaminants on the degreased part and the bath must be disposed of and replaced.

4.1.4 Frequently Review All Water Costs

Shipyards often separately assess the costs of water supply, pretreatment and wastewater treatment as parts of specific production processes. Knowing the total cost of water from cradle to grave is relevant for a shipyard whether it treats and discharges its own water, or discharges to a municipality. The varied uses of water are components of an often intricate, intimately linked set of systems beginning with water supply and ending with wastewater treatment and final disposal or reuse. Consider the combined costs associated with obtaining water, using water and treating water as it relates to production.

The true cost of water per unit of production considers the costs directly related to supplying, using, treating, and disposing of water at a shipyard. In order to do this, the water system cost must be broken into its components, then applied to each item for a specific time period (daily, monthly, annually). Only when the components of cost for the system are known and identified, can one evaluate the impact of system change (e.g., increased reuse or adding a new production line). Consider the following list of costs when evaluating options and developing appropriate solutions for optimizing water management:

- Water bill,
- Pretreatment (e.g., softening, particle filtration, etc.),
- Energy (pretreatment, pumping, heating and cooling),
- Labor (operators, maintenance, and associated benefits),
- Laboratory tests and testing supplies,
- Permits,
- Wastewater treatment,
- Reporting fees,
- Offsite disposal,
- Other environmental, health and safety costs.

Changing a process may not be cost effective after the cost of the wastewater treatment is considered. On the positive side, small adjustments to water management within the plant can provide major impacts for reducing water treatment costs. Segregating and treating low-flow, high pollutant load waste stream can bring stressed treatment systems to within capacity. This relatively small change can extend system life and allow for additional production growth at a fraction of the cost. However, it is critical to evaluate the difference in cost between the current system and the proposed changes. A net-present-value (NPV) analysis is always helpful in evaluating the long-term costs of several alternatives.

Consider within the cost "goodwill". In reality, water costs, water supply, and water treatment constraints limit regional growth and expansion. For example, take credit if the shipyard discharges wastewater to a publicly owned treatment works (POTW); Reducing discharges to the POTW thereby delays the POTW's need for costly upgrades. Determining water costs helps a water system run as efficiently as possible, and it improves the competitiveness, as well as lays the foundation for sustainable future growth.

4.2 Lessons Learned during Project Survey

4.2.1 Typical Process Wastewater Streams for Potential Recycling

The results of the project shipyard surveys identified various wastewater streams for potential recovery and reuse. They are listed below according to the shipyard manufacturing process that generated them. This list does not include every potential stream, and therefore add other process wastewater streams when their volume or contaminant level has a significant environmental or economic impact.

Acid Cleaning

Acid treatment is used to chemically prepare the surface for paint adhesion. Treatment is conducted using a series of dip tanks in which the workpieces are typically immersed in acid, rinse water, and a rust preventative solution. In the shipbuilding industry, this process is primarily used for preparing pipe systems and small workpieces for the painting process.

Water Use: After treatment in acid, water is used to rinse the surface.

Alkaline Cleaning for Oil Removal

Alkaline cleaning is conducted primarily to remove oil from a metal surface during surface preparation. These aqueous-based cleaners, can be brushed or sprayed onto the metal surface or, as is most commonly done, applied using a dip tank.

Water Use: After cleaning, water is used to rinse the surface.

Aqueous Degreasing

Aqueous degreasing is conducted to remove greases and other contaminants from the surface of a metal. This process involves using a water-based solution, which contains detergents. This process has increased in use recently because of the stringent regulations associated with conventional solvent degreasers.

Water Use: The cleaning solution is water based and the workpieces are typically rinsed with water after cleaning.

Chemical Milling/Machining

This process involves using chemicals to attack or etch the surface of the workpiece resulting in the removal of metal.

Water Use: Water is used to rinse the metal during this process.

Chromate Conversion Coating

The chromate conversion coating process is used to chemically convert a metal surface to produce a protective oxide layer.

Water Use: Water is used as a rinse after the conversion process.

Corrosion Preventive Coating

This process involves applying a coating to the surface of a metal to prevent corrosion, often a zinc primer coating.

Water Use: A water curtain is used to capture primer overspray.

Deballasting

This process involves removing all the water from the ship's ballast. This water is usually contaminated with oils and greases.

Water Use: The water that is removed from the ballast becomes the waste stream.

Developing, X-ray Films

X-ray films are used during the inspection process usually to find weld or other defects. The film is usually processed on-site, necessitating chemicals baths for the development and printing of the photographs and X-rays.

Water Use: Water is used to rinse the film and photographs/X-rays after they are removed from the chemical baths. The rinsing process stops the chemical reaction that is taking place in the baths.

Heat Treating

Heat Treatment is conducted to impart certain physical properties, such as strength and hardness, to a metal workpiece that is being fabricated into components used in the shipbuilding process.

Water Use: During heat treatment, water is used to cool the metal workpiece. This is known as quenching.

Insulation and Flooring

Installation of insulation and flooring materials.

Water Use: Water is used to clean the worker's hands and the tools used to install these materials.

Painting

Painting is applied to ships and component surfaces to prevent corrosion and deterioration and is one of the most common processes in all industries. However, it is especially important in the shipbuilding industry because of the extreme detrimental effects of the marine environment. The spraying of paint results in an overspray, which is caused by the low transfer efficiency of this method. Therefore, painting is conducted in a spray booth and at these shipyards, the overspray is captured by a water curtain which results in a wastewater stream.

Water use: To capture paint oversprays with a water curtain and for rinsing and clean up.

Pipe Bending

This process involves heating sections of a pipe to bend and form into specific shapes. One side of the pipe is heated and the other side is cooled with water.

Water Use: Water is used to cool the pipe during the heating and forming process.

Pipe Flushing

Pipes are flushed as a final cleaning step to remove any contaminants that may be inside the pipes such as dirt, welding flux, etc.

Water use: Used to flush the pipes.

Pipe Hydrotesting

Pipes are pressure-tested using water to ensure that joints such as welds will not leak.

Water use: Used to conduct the pressure testing.

Plasma Arc Cutting

Plasma arc machining removes metal from a workpiece using a plasma arc. This process is conducted with the workpiece immersed under water to keep the workpiece cool.

Water use: As a coolant for the workpiece being machined by plasma arc.

Plasma Arc Welding

Plasma arc welding uses a plasma arc to weld two pieces of metal together. This process uses water to keep the workpiece cool.

Water use: As a coolant or to rinse the workpiece being welded by plasma arc.

Soldering/Brazing

Metal workpieces are soldered or brazed by using a metal filler to join two metal pieces together with a strong bond.

Water use: As a coolant for the workpiece being joined or as a quench.

Storm Water

Water, which is accumulated during a rainstorm, contains various contaminants from the shipyard such as oils and greases.

Water Use: The resulting contaminated rainwater is the waste stream.

Stripping/Hydroblasting

This process is primarily used for paint, marine growth, mud, and saltwater removal. High-pressure water is used, sometimes with a small amount of rust inhibitor, to remove these contaminants from the ship's hull. This process is often followed by air blasting which acts as a final surface preparation.

Water Use: Water is used as the blast medium.

Thermal Cutting

This process uses an oxy-acetylene oxygen lance, electric arc cutting tool, or laser to cut through metal.

Water use: Water is used to cool or rinse the metal workpiece.

Washing/Steam Cleaning

Both high-pressure washing and steam cleaning are used during surface preparation to remove grease, oil, and other contaminants. These processes are used more frequently now than in the past because of recent regulations restricting the use of solvent cleaning. Water is used in the form of steam, often with added detergents, to clean surfaces. This process also makes use of heat to clean surfaces. High-pressure washing makes use of pressure to clean various surfaces.

Water use: Water is integral to both of these processes.

Wet Air Pollution Control

Contaminated air is removed from a work area, cleaned and returned as fresh air. The water is used to scrub the air clean of contaminants.

Water Use: The waste stream is water containing the contaminants, which have been removed from the air.

4.2.2 Data Collection

The survey attempted to gather numerous data on the waste streams. However, it was found that not all of this data was available for each waste stream for various reasons such as lack of data collection on the part of the shipyard or inability to locate appropriate records. The survey attempted to gather the following pertinent information:

- processes which generated the wastewater;
- quantity of wastewater generated;
- contaminants; and
- disposal methods of the wastewater.

Actual data gathered during the three project surveys is summarized in Table 1 in Appendix C; this is included to illustrate data gathering problems that a shipyard may encounter.

Many waste streams were not included in the survey because the shipyard felt the small quantity generated did not warrant their time to collect data on the stream. Typically, it is not economically beneficial to recover and reuse small wastewater streams unless disposal costs are very high. Also, some of the shipyards contract out certain production work and therefore, no wastewater stream is generated at their facility. In addition, not every process is conducted at each shipyard. These three reasons account for why most of the processes are only listed as being conducted at one or two of the shipyards even though they produce similar products.

Efforts were made to determine the quantity of each waste stream but, in many cases, this proved to be difficult. Often, however, the flow measurement and chemical analyses were done only at the on-site WWTF, and consisted of many waste streams combined together. When two or more waste streams are mingled together, a measurement of specific waste streams could only be estimated. As mentioned above, contaminant data was only located for some waste streams. This data usually was obtained from summarized laboratory analysis reports, which are required by the regulatory agencies.

Discharge methods were easy to obtain since the shipyards are well aware of where they discharge each of the waste streams. Data also exists on the costs for various discharge methods (POTW, contractor hauled, discharge to surface water). It would probably be beneficial to only determine the flow rates after the list is narrowed down to a smaller number or potential wastewater streams for recover and reuse. For some applications, this parameter is of lesser importance than those parameters summarized in this report.

The data obtained from the survey was used to prioritize waste streams for the demonstrations. Factors that were considered include: largest quantity streams, waste streams being discharged directly to surface water, hazardous waste streams, waste streams containing contaminants at levels near discharge limits, waste streams with a high probability of successful recycling, and any waste streams that cause a particular problem for the shipyard.

4.2.3 Data Analysis

Once survey results were obtained, a method of prioritizing these streams for demonstration purposes was determined. Initially the largest waste streams were identified since these are usually the most feasible to recover and reuse. These included: cleaning, deballasting pipe bending, flushing and testing; storm water; and stripping/hydroblasting; wet air pollution control; and various washing processes.

It is important to note that although storm water is often a large waste stream at shipyards, it is often a very difficult stream to recycle. Storm water, even treated storm water, is not normally recycled for any purpose. Usually, recycled water is used industrially for plant operations such as cooling water, scrubber make-up water, etc. Storm water, because it is dependent on weather events, is not a continuous source of water. In addition, collection of the storm water for treatment and for distribution to reuse after treatment would be costly and complicated. Because of these factors, it is doubtful that treated storm water would serve a useful purpose as recycle water.

The next group considered was waste streams discharged either directly to surface water or treated and then discharged to the surface water. These types of waste streams are targeted because it is believed that discharging these waste streams to surface water will become increasingly more restricted in the near future.

The third group considered is hazardous waste streams that are hauled off-site for disposal. This group is important because the disposal costs can be quite high. Being able to recycle these streams would potentially result in large costs savings.

The final considerations given were to specific wastewater contaminants and water quality limits and any particular problematic waste streams for the individual shipyard.

Although quantities were not available for all waste streams at each shipyard, reviewing these data indicates that the largest quantity waste streams are a result of several processes. These are: acid cleaning; alkaline cleaning; aqueous degreasing; deballasting; pipe bending, flushing and testing; storm water; stripping/hydroblasting; wet air pollution control; and various washing processes.

Table 2, below summarizes the initial list of waste streams that were considered for reuse during this project.

Table 2. Priority List of Project Wastewater Streams

Process Generating the Wastewater Stream	Reason for Inclusion on Priority List
Acid Cleaning	LQ[1], HW[1]
Alkaline Cleaning	LQ, HW
Aqueous Degreasing	LQ, HW
Chemical Milling/Machining	LQ, HW
Deballasting	LQ, SW[1]
Painting	LQ, HW
Pipe Bending	LQ
Pipe Flushing	LQ
Pipe Testing	LQ, SW
Stripping/Hydroblasting	LQ, SW
Wet Air Pollution Control	LQ
Washing	LQ
Thermal Cutting	SW
Plasma Arc Welding	SW
Heat Treating	SW

[1]Key: Large Quantity – LQ; Discharged to Surface Water – SW; Hazardous Waste – HW

5.0 POTENTIAL RECOVERY/REUSE TECHNOLOGIES

The use of novel separation technologies to treat wastewater has grown immensely in recent years. Technologies for shipyard wastewater recovery and reuse include membrane electrolysis, ion exchange, reverse osmosis, vacuum evaporation, micro/ultrafiltration, and diffusion dialysis. Each of these technologies and the criteria for their selection will be described in this section of the manual. Other technologies can be considered variations of those described (e.g., automatic back-flush filters, liquid ion-exchange, air-sparged hydrocyclone, and vibration membrane separators). These technologies have been demonstrated successfully elsewhere, and are robust enough for a wide variety of manufacturing activities at the shipyard.

5.1 Technology Capabilities

With the exception of ion exchange and vacuum evaporation, the potential recovery/reuse technologies listed are based on membrane technologies. Membrane separation technologies that were once primarily used to purify water for selected industrial applications, which required ultra-clean water are now being used for both industrial and municipal wastewater treatments. Today's membranes are capable of operating under a wide range of operating temperatures and chemical environments and it is now possible to be more selective in the materials to be separated. Similarly, ion exchange resins and vacuum evaporation materials of construction have diversified for wider applicability. Today's recovery/reuse systems have resulted in lowered costs for previous operations for which they were used and are applicable to new operations. It is now possible to apply membrane technologies to most applications that require separation from liquids and gases. These recovery/reuse technologies are finding their way into shipyard operations that require efficient chemical separation, purification, concentration, and fractionation.

Typically, each recovery/reuse technology is integrated with marginal pretreatment capability (e.g., particle filtration, free-phase separation, and solute adsorbant) to protect the system components and membrane fouling. Membrane fouling is broadly classified into two categories: the reversible and irreversible. Reversible fouling occurs due to the concentration polarization of materials at the membrane-rejecting surface that can be removed by appropriate cleaning. Irreversible fouling occurs by both chemical (chemisorption) and physical (pore plugging) mechanisms.

If the wastewater is heavily contaminated, particularly as a result of co-mingling of more than one wastewater, then other pretreatment systems must be added to these off-the-shelf systems. Most technologies, by themselves, do not recover shipyard industrial water and aqueous solutions. Industrial water recovery and reuse are possible when conventional and advanced treatment technologies are combined. Variations of traditional wastewater treatment systems remove gross contaminants (e.g., free, non-emulsified oil, grease and visible particulates), while specialty technologies recover the solution from the interfering contaminants that remained.

5.1.1 Diffusion Dialysis

Diffusion is a process in which a solute moves from an area of higher concentration to an area of lower concentration. Dialysis is a phenomenon in which a solute in solution permeates through a selective membrane. Therefore, diffusion dialysis is based on the natural diffusion of ions across a semipermeable membrane from a region of higher concentration to a region of lower concentration (Figure 1).

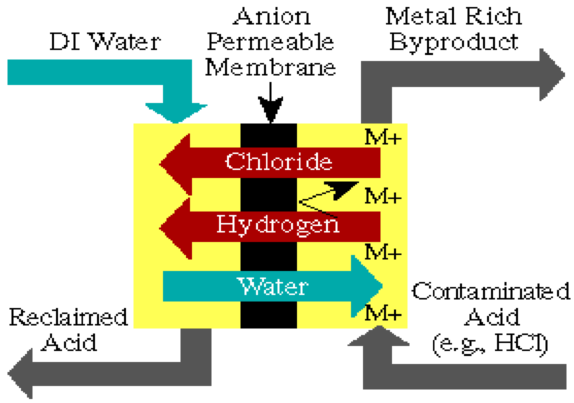


Figure 1. Diffusion Dialysis

Diffusion dialysis is used to purify and recover acids (e.g., hydrochloric, nitric, sulfuric, and hydrofluoric) that have been contaminated with metal ions such as iron, chromium, and nickel. The process is capable of recovering 80 to 95 percent of the initial acid and rejecting 60 to 95 percent of the contaminant metal.

Anion exchange membranes are used in systems designed for the recovery of mineral acids from contaminated acid/salt solutions. The law of electroneutrality requires that ionic charge neutrality is maintained on both sides of the exchange membrane. Thus, either anions must exchange through the membrane at an equal rate in both directions, or each anion that diffuses must be accompanied by an associated cation. Due to the extremely small size of the hydrogen cation, it is able to migrate easily through the membrane in conjunction with an anion, such as chloride, fluoride, nitrate, or sulfate. The comparatively large metal ions are inhibited from associating with the diffusing anions. However, “leakage” of metal ions does occur.

The rate of metal leakage and the rate of acid recovery are functions of solution-membrane contact time. The recovery equilibrium is controlled by the solution flow rates. Slower solution flow rates will maximize the percent of acid that is recovered, but cause a higher leakage rate. Faster solution flow rates will maximize the throughput volumes and minimize the metal leakage rate, but at the expense of recovery efficiency. A balance that maximizes the percent recovery of acid and minimizes the percent leakage of metal ions is desirable.

5.1.2 Ion Exchange

Ion exchange is a process in which dissolved ions of a spent solution are attracted to negatively or positively charged sites on the surface of an insoluble solid (in this case, a resin bed). This process is shown in Figure 2 (configured for acid recovery).

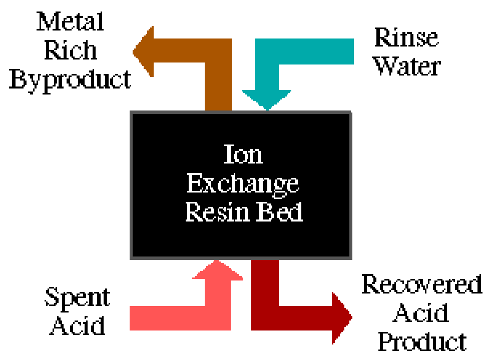


Figure 2. Ion Exchange (Scheme for Acid Recovery)

In ion exchange, solution containing dissolved ions is introduced into the resin bed specifically selected to attract either positively charged ions (cation resin) or negatively charged ions (anion resin). As the solution passes through the bed, ions are removed from the solution and deposited on the surface of the resin bed.

The resin bed has a limited capacity to hold attracted ions. Therefore, a regeneration step is necessary to remove the ions from the surface of the resin and leave its charged sites open for further processing. This is accomplished by flushing the resin bed with an acid, caustic, or salt solution. The regenerant solution is selected for its capacity to strongly attract and remove the ions deposited on the resin bed.

The mobile ion exchange unit is an automated system with four resin beds connected in series. Specific resins or sequences of resins are changed manually. Regeneration of any of the resin beds can be performed on-line or off-line. However, regeneration cannot be performed while processing a solution.

Ion exchange removes dissolved ions from liquids and is capable of recovering a wide variety of mineral acids from spent electroplating solutions, achieving acid recovery efficiencies of greater than 95 percent. It is also used to treat raw water and polish wastewater.

5.1.3 Membrane Electrolysis

Membrane electrolysis is an electrochemical process that uses electrically charged membranes and an electrical potential difference to separate and concentrate a variety of salts, acids, and bases from aqueous solutions. This process for a two-compartment cell is shown in Figure 3.

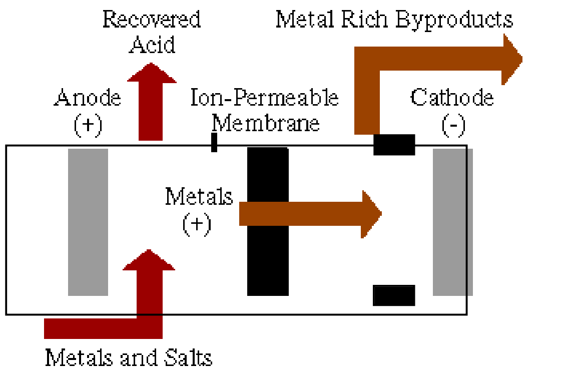


Figure 3. Membrane Electrolysis

Process solution is prefiltered using a 5-micron nominal particle filter and granulated activated carbon (GAC) cartridges. A direct current is applied via the rectifier between the anodes and cathodes. The cathode reaction varies depending on the metal and its concentration in the stream. If the metal is completely reduced (to zero valence), it is plated onto the cathode structure and removed from the stream. If the reaction precipitates a metallic hydroxide, the filter on the catholyte stream removes it.

There is significant flexibility with membrane electrolysis, depending on the type of solution reuse or rejuvenation desired. For example, tri-valent chromium could be reoxidized to chromate at the anode. A third compartment may be added to isolate the anode, when the ions (such as chloride) could oxidize to form a noxious gas. Membrane electrolysis may be used in conjunction with auxiliary skids containing a feed tank and an auxiliary holding tank, or it can be directly connected to plating tanks and an auxiliary holding tank. The two- and three-compartment configurations are suited for concentrated finishing baths, such as etching, anodizing, and stripping solutions, whereas the multi-membrane stack configurations are suited to remove dissolved salts from dilute rinse waters.

5.1.4 Micro/Ultrafiltration

Microfiltration and ultrafiltration are based on the same principle, but achieve different particle size separations. Microfiltration is well suited to separate larger sizes, such as suspended solids, particulates, and bacterial microorganisms. Ultrafiltration applies to particles from 0.005 to about 0.1 microns (e.g. latex/emulsions, large-molecular dyes, viruses, etc.).

Separation is performed using a microporous membrane as shown in Figure 4. Wastewater is sent through the membrane under pressure. Suspended solids and emulsified oil are rejected by the membrane and removed as concentrate. The filtered water passes through as permeate. The concentrate is recirculated through the membrane until the permeate flow rate drops.

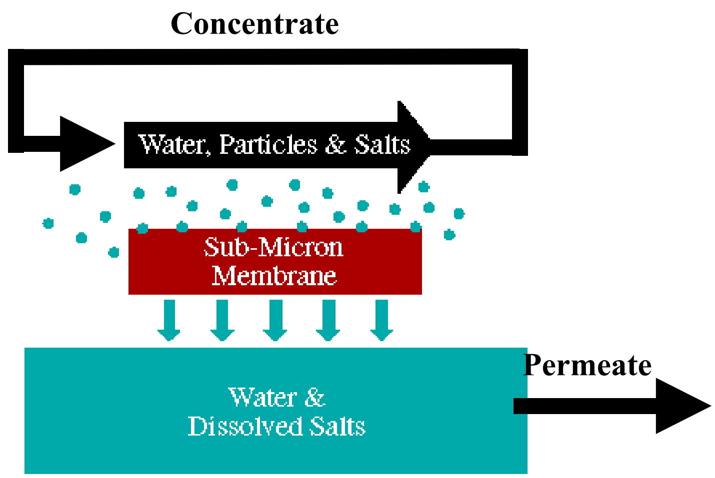


Figure 4. Micro/Ultrafiltration

As the filtration process proceeds, the internal surface of the filter membranes will become contaminated with particles, reducing the permeate flow. Backpulsing (or vibration, or another mechanical process) is used to prolong the useful life of the filters. During backpulsing, pressure is applied to the permeate side of the filter to drive clean permeate backwards through the membrane, thus clearing the internal membrane surface and pores. Backpulse volume, frequency, and duration may be optimized for each fluid/filter combination.

In traditional membrane filtration systems, tangential flow is used to create the shear force required to eliminate fouling and drive permeate through the membrane. The process or waste liquid streams are pumped at high velocities and pressures to create the shear force at the membrane surface. There are now alternative technologies for the treatment of high viscosity materials. These include membrane filters with rotational induced shear (CR Membrane Filter and Spintek) and vibrational induced shear (VSEP by New Logic) to provide an alternative to tangential flow membranes for removing solids and fouling materials from the surface of the membranes. This allows for lower pressure requirements to maintain liquid flow through the membranes, which allows for treatment of more viscous liquid streams.

Micro- and ultrafiltration are used to extend the life of process solutions, such as alkali cleaning or stripping solutions. They are also used for recovering paints from rinse waters and to remove most inorganic suspended solids and emulsified oils from process solutions and rinsewaters.

5.1.5 Reverse Osmosis

Reverse osmosis (RO), also called hyperfiltration, is capable of the highest degree of filtration possible. This technology uses a 1 to 20 Angstrom semi-permeable membrane to separate ionic substances in a cross flow filtration process (Figure 5).

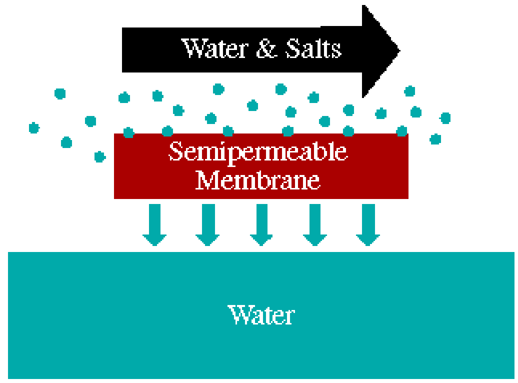


Figure 5. Reverse Osmosis

RO systems typically pre-filter the process solution using granulated activated carbon and 5 micron particle filters. Many systems connect two cross flow RO filter modules in series to improve either the rejection of the salt from the water, or the percent recovery of the water. Process parameters that affect filtration efficiency include concentrate flow rate, inlet pressure, trans-membrane differential pressure, and fluid temperature.

As the filtration process proceeds, the internal surface of the RO membranes become fouled with particles and colloidal material, reducing the permeate flow. A chemical cleaning process is used to clean the membranes. Cleaning frequency for RO equipment can be estimated. Manufacturers generally recommend that the membranes should be cleaned if the normalized product flow decreases by 10 to 15 percent, or if the pressure differential increases by 10 to 15 percent.

RO is capable of separating dissolved salts and removing bacteria, pyrogens, and organics from water. It is often used as part of a system to recover plating chemicals, heavy metals, and dilute organics from aqueous, spent bath solutions and rinse waters. Other industrial applications include boiler feed purification and blowdown reclamation, dye purification, coolant recovery, desalting of brackish wastewater, and marginal reduction of biological and chemical oxygen demand in waste streams.

5.1.6 Vacuum Evaporation

Vacuum evaporation uses a simple principle to separate water from salts and metals. Water vaporizes at 100°C (212°F), while dissolved salts and metals do not. Unfortunately, some chemicals degrade at this temperature. In a vacuum, however, water boils at lower temperatures, so water and chemicals can be separated without degradation of the chemicals. Both the water and the chemicals can then be recovered and reused. The vacuum evaporation process is shown in Figure 6.

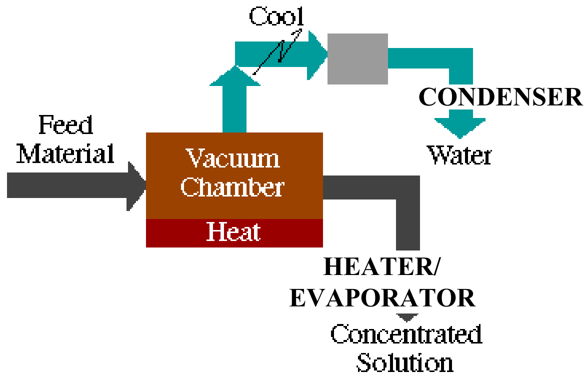


Figure 6. Vacuum Evaporation

The vacuum evaporator operates at a residual pressure of approximately 40 mm Hg. Thus, solutions to be treated boil at a temperature of approximately 38°C (100°F). An almost complete separation of the solvent from the solute is possible. The yield of the system depends on the physical characteristics of the chemicals present and their concentration in the solution to be treated.

Vacuum evaporation is typically used to recover plating chemicals from rinse water or to concentrate waste streams prior to disposal. The concentrated wastes may then be either discarded or recovered and reused.

5.2 Selection Criteria

In most cases, selection of the technologies for water reuse depends on the validity of the completed shipyard water survey (Section 4). The water treatment technologies need to economically match the influent/effluent characteristics and other requirements of the wastewater. To select appropriate recovery/reuse technologies, compare competing technologies in terms of performance capabilities, production of residues, overall costs, and operation and maintenance requirements.

5.2.1 Performance Capabilities

The system design will be dictated by past applications of similar systems and the pilot study information. Examples of past applications are listed in Table 3 and specific examples are summarized below the table.

Table 3. Applications and Limitations for Recovery/Reuse Technologies

Technology Description	Typical Applications	Limitations
Diffusion Dialysis Anion permeable membrane between a concentration gradient.	• Acid recovery • Metal recovery (with electrowinning)	• Fouled by suspended solids • Possibility of precipitating metals, clogging the system • Best suited for simple acids
Ion Exchange Exchanges dissolved ions at strong or weakly charged surfaces.	• Acid recovery • Polish wastewater • Metal recovery (with electrowinning)	• Oils can coat granules and blind them • Suspended solids can foul the system
Membrane Electrolysis Ion permeable membrane(s), between a voltage gradient.	• Regenerate metal finishing baths, acid etching, and acid stripping.	• Oils tend to coat ion permeable membrane • Match configuration to the anions to avoid forming hazardous gaseous vapors
Micro- and Ultra-filtration Separation based on particle size through a ceramic or plastic porous membrane. MF: 0.1 to 0.8 micron UF: 0.005 to 0.1 micron	• Regenerate alkaline cleaning solutions • Remove inorganic suspended solids, tramp oil, greases, and emulsions	• Backpulsing (or another mechanical method) may be required to clean and/or prevent membrane fouling
Reverse Osmosis Separation based on contaminant charge and size (>1 to 20 Angstrom) through a semi-permeable membrane.	• Metal recovery • Coolant recovery • BOD/COD reduction	• Cannot tolerate significant concentrations of suspended solids • Free oily solution can foul membrane quickly.
Vacuum Evaporation Low temperature/low pressure vaporization	• Waste stream concentration • Chemical recovery from rinse water	• Not well suited for solutions heavily concentrated with suspended solids

<u>Examples of Past Applications</u>

1. An aircraft engine manufacturer uses diffusion dialysis to recover concentrated nitric acid from a metal passivation process.

2. A steel coil manufacturer reuses water in its pretreatment operation. A deionized (DI) closed-loop system supplies water as the final rinse for steel parts pickling. The acid regenerant for the cation resin is used in the pickling bath.

3. A steel pickling operation is using membrane electrolysis as part of an operation to recover the pickling solution. The membrane electrolysis splits the sodium sulfate salt generated by the process, back into the sulfuric acid pickling bath and caustic used for neutralization of sulfuric acid in its treatment process.

4. A semiconductor wafer fabricator applied water pinch (incremental water reuse) principles to reuse wastewater from their plating lines, for cooling tower water. The wastewater was microfiltered, and blended with fresh deionized water. Water use was reduced by one fifth. Microfiltration systems are also used in the metal plating operations to reduce the concentrations of heavy metals such as cadmium, chromium, and mercury in wastewater. Ultrafiltration systems are being used to treat oily wastes from a variety of metalworking operations.

5. As part of the permit to build a co-generation facility, the Cedar Bay Power Company had to use water from an adjacent pulp and paper mill as cooling tower water. After cycling 4-5 times in the cooling towers, the blow-down was to be fed to a reverse osmosis (RO) system for concentration prior to evaporation and crystallization. The silt density index (SDI) of the blowdown was not measurable, so a nanofilter was installed in front of the RO to remove color, suspended solids, and sulfates prior to the processing with the RO. The nanofilter is a feed and bleed design operating at 85% recovery. But more importantly, the permeate is of such high quality and of reduced salt that the subsequent RO operates at 75% to 80% recovery thereby reducing the load on the evaporators and cyrstallizers. The nanofilter has been on line for 7.5 years. They only replaced half of the nanofilter membranes during the first 3.5 years.

6. The Phelps Dodge Rod Mill in El Paso, Texas, has been on line for 12 years. Prior to installing the membrane system, the Rod Mill precipitated the copper and land farmed the water from the precipitation system's filter press. The membrane system concentrates the copper and acid with an acid resistant RO membrane system. The concentrate is fractionated using NF into copper at 30 g/l and acid at 10%. Both of these streams are reused. Permeate from the first RO system is further polished with another acid resistant RO system, upon which the water is reused as rinse. The concentrate is sent back to the feed of the copper and acid mixture for further recovery. The savings in copper, water, and acid result in a payback on the equipment of less than one year. Element life has averaged 2.5 years.

7. A Middle East manufacturer of aluminum cans recovers water contaminated with hydrofluoric acid, dissolved aluminum, and various oil/surfactant complexes at a pH <2. The treatment unit incorporates ultrafiltration, nanofiltration, followed by reverse osmosis. It recovers 88% of the process water. The concentrate from the RO membrane contains higher purity hydrofluoric acid for reuse. This facility hauls water for its supply, and so the cost of fresh water transport is high.

8. Toyota Motor Manufacturing, Kentucky, monitored 200 collection sumps to find that 3 of those sumps were the source of 99% of the nickel and zinc in the wastewater. They segregated those sumps, treated the water with calcium hydroxide (lime) to precipitate the metals and concentrated the precipitate with an ultrafilter. This is not an example of reuse, but it is an example of segregating wastewater to limit the treatment equipment requirements.

9. A fabricator recovers an iron phosphate-based cleaner used for aluminum furniture. They use ultrafiltration to remove particles and oil and grease (O&G). In addition, they found that this treatment lowered the contaminant drag-out and therefore slowed the rate of process rinse water contamination.

10. An industrial refrigeration, air conditioning and heat exchange equipment manufacturer recovered cleaning solution for reuse. The first-stage acid cleaner is continually ultrafiltered to remove particles and O&G, extending the life of the cleaner indefinitely (eliminating regular batch dumps). The second stage rinse water and third stage caustic cleaner is also ultrafiltered periodically.

11. A job-shop using screw machines and CNC lathes generates oily wastewater from washing the shop floor. The floor cleaning solution is recovered with a membrane filter where the O&G and particles are removed, and the filtered cleaner is held until the next floor cleaning. New cleaning solution is added to the reclaimed cleaner to make up for any losses that may have occurred, for the next floor cleaning.

12. Ford Motor Company's Romeo Engine Plant uses ultrafiltration to treat emulsified oily wastewater, as an alternative to chemical de-emulsification. This improved the removal performance reliability (regardless of raw influent emulsified oil concentration), and eliminated chemicals for de-emulsification. However, pilot tests to concentrate the skim oil using cross-flow ultrafiltration were not encouraging. Dissolved metals (copper, nickel, lead and zinc) were not removed, but precipitated later by chemical treatment.

Table 4 shows how these technologies tentatively match general requirements for shipyard wastewater recovery/reuse. Again, explore the technical limitations of these technologies (some of which were noted in Table 3, and handled by pretreatment). One of the most important design considerations for any recovery system is that of pretreatment. Keep in mind that pretreatment may be required before removing the target contaminant. Consider the general physical/chemical processes listed in Table 5 as the most likely pretreatment and after treatment options for water reuse.

Table 4. Technologies for Shipyard Wastewater Recovery/Reuse

Typical Shipyard Process	Recovery Technology(ies)
Acid Cleaning	Nanofiltration or reverse osmosis (RO) on rinse
Alkaline Cleaning (Oil)	Micro- or Ultrafiltration on cleaner
Aqueous Degreasing	Micro- or Ultrafiltration on degreaser
Chemical Milling/Machining	Membrane electrolysis on acid; Nanofiltration or RO rinse
Chromate Conversion Coating	Reverse Osmosis (PVDF material) on rinse
Corrosion Prevention Coating	Hydrocyclone/centrifuge/filter on water curtain
Deballasting	None. Treat with an efficient O/W separator/metals treat
Developing, X-ray Films	Vacuum evaporation
Heat Treating	Reverse osmosis
Industrial and Flooring	None for recycle (due to industrial hygiene requirements).
Painting	Hydrocyclone/centrifuge/filter on water curtain
Pipe Bending	Reverse Osmosis
Pipe Flushing	Air-sparged hydrocyclone or nanofiltration
Pipe Hydrotesting	Nanofiltration
Plasma Arc Cutting	Centrifuge
Plasma Arc Welding	Centrifuge
Soldering/Brazing	Reverse osmosis
Storm Water	None economical for industrial purposes
Stripping/Hydroblasting	Reverse osmosis
Thermal Cutting	Centrifuge
Washing/Steam Cleaning	Micro- or Ultrafiltration on cleaner
Wet Air Pollution Control	Nanofiltration

Table 5. Selection Criteria for Wastewater Treatment Technologies

(Physical/Chemical Processes)	Dissolved Organics	Free Phase Organics	Suspended Colloidal Solids	Dissolved Heavy Metal Salts	Mineral Acids	Alkaline Cleaners
Particle Filtration						
Microfiltration	O	–	+	O	O	+
Ultrafiltration	O	–	+	O	O	+
Dialysis						
Diffusion Dialysis	–	–	–	O	+	/
Electrodialysis/deionization	–	–	–	+	+	/
Membrane Electrolysis	–	–	–	+	+	/
Semipermeable Pressure Filter						
Nanofiltration	/	–	–	+	O	/
Reverse Osmosis	/	–	–	+	+	/
Extraction/Adsorption						
Strong Anion/Cation	–	–	–	+	O	/
Weak Anion/Cation	–	–	–	+	O	/
Selective/Chelating Resins	–	–	–	+	O	/
Acid Sorption	–	–	–	O	+	/
Liquid Ion Exchange	/	–	–	+	O	–
Activated Carbon (as is)	+	/	–	O	O	/
Activated Carbon (treated)	+	/	–	+	O	/
Zeolites/Activated Alumina	/	–	–	+	/	/
Distillation						
Atmospheric Evaporators	+	+	/	+	+	O
Vacuum Evaporators	+	+	/	+	+	O
Specific Gravity Separators						
Coalescing Filters	O	+	O	O	O	O
Inclined Plate Filters	O	+	O	O	O	O
Centrifuges	O	+	+	O	O	O
Cyclones	O	+	+	O	O	O
Foam Separators	+	/	+	+	O	O

+ = Applicable Process for Wastewater Treatment (general, given materials compatibility)
O = Minimal Effect on Process, given materials compatibility
/ = May Foul Process
– = Fouls Process
Also, keep in mind that in each of these cases, there are significant operational variations within each technology (e.g., vibratory and centrifugal membranes).

Pay particular attention to the following water characteristics:

- Free oils tend to coat membrane surfaces and severely inhibit recovery. Forms of coalescers, located between the equalization tank and the membranes, usually accomplish the desired removal.
- Coarse solids and inert materials in the wastewater can mechanically damage membranes. They also add excess capacity requirements to the system. Install a self-cleaning screen between the equalization tank (or coalescer) and the membrane feed.

- If dissolved solids are within their limits for insolubility, and can precipitate, then upstream chemical precipitation is recommended. However, the addition of polymers is not recommended due to the fact that residual polymers will tend to adhere to the membranes and promote fouling.

- pH, oxidation/reduction potential, and temperature of the solution should be compatible with the materials of construction, which can chemically and physically withstand the variations in these parameters.

5.2.2 Production of Residues

Separation processes are just that – the material that is no longer part of the purified water becomes part of another, separate stream. It does not just go away. And if this concentrated stream cannot be reused, then it becomes a waste. The volumes and concentrations of this waste are important factors to be considered.

All of the recovery/reuse technologies create residues that need to be addressed. For example, if reverse osmosis recovers 80% of 20,000 gallons from wastewater, then 20%, or 4,000 gallons of the wastewater is part of a waste concentrate. On the positive side, the reverse osmosis purified 16,000 gallons of wastewater for reuse. However, if that 4,000 gallons cannot be reused, then it becomes a residue from the reverse osmosis process, requiring waste disposal. Further, if that concentrate contains contaminants above characteristic waste thresholds, then the concentrate becomes a regulated hazardous waste. Recovery systems are selected not only to minimize the generation of waste volume, but also to minimize the hazards of the waste to be disposed.

Another example of residue generation concerns diffusion dialysis, described in Section 5.1.1. Typically, the diffusion dialysis process is fed equal flows of both contaminated acid and a new feed stream of purified water. The diffusion dialysis process discharges approximately equal amounts of reclaimed acid and metal rich (acidic) byproduct, which approximately equals the feed flow of contaminated acid. There is no reduction in waste volume. Therefore, diffusion dialysis is a bath maintenance process that is justified for its ability to recover a valuable product (e.g., acid) and reduce waste treatment costs for acid neutralization.

Residues are also produced when the recovery system undergoes maintenance cleaning. Recovery system maintenance cleaning is necessary to remove the accumulation of contaminants from within the system packing, filters, and adsorbent materials. These residues from system maintenance cleaning can add up to significant quantities for disposal (or reuse – see Section 5.2.1 example 2, which reuses the ion exchange regenerant for pickling bath make-up). The cleaning chemicals and water use for system maintenance cleaning should be quantified for the selection criteria. Table 6 gives estimates for residue generated during cleaning of the recovery systems.

Table 6. Maintenance Cleaning Residue

Technology	Cleaning Residue	Frequency
Diffusion Dialysis	1 gallon flush/gpd-unit	Monthly
Ion Exchange	100 gallons regen/gpm-unit	Monthly
Membrane Electrolysis	10 gallons cleaning/gpm-unit	Monthly
Micro- and Ultra-filtration	10 gallons cleaning/gpm-unit	Weekly
Reverse Osmosis	10 gallons cleaning/gpm-unit	Weekly
Vacuum Evaporation	1 gallon cleaning/gpd-unit	Weekly

gpd = gallons per day; gpm = gallons per minute

In general, ion exchange generates the most residues (from backwash, anion and cation regeneration, fast rinse and slow rinse). Reverse osmosis and membrane filtrations generate significant amounts of residues from maintenance cleaning, but not as much as ion exchange does.

5.2.3 Overall Costs

To optimize water reuse and minimize its costs, try to understand all the water system components. Next, measure or estimate their associated costs and benefits. Once the true economics related to all aspects of water is known, it is easy to calculate the value per unit of production. This value of water per unit of production can be tracked easily.

As part of this project, *CTC* performed an economic analysis of recovery/reuse systems[1].

A general summary of costs is given in Table 7. Capital costs will follow the six-tenths power rule:

$$\text{Capital}_{\text{FLOW-A}} = \text{Capital}_{\text{FLOW-B}} \times (\text{Flowrate}_{\text{A}}/\text{Flowrate}_{\text{B}})^{0.6}$$

[1] Note that some costs are site-specific. For example, water treatment facilities vary in their physical layout, floor space, treatment capacity, current equipment usage, and materials and labor costs. Consequently, the costs and savings will vary from site to site. A specific site cost evaluation may be needed to determine its cost/performance.

Table 7. Cost per Unit of Water Produced

Technology	Capital	O&M
Diffusion Dialysis	$15,000/7.5 gpd	$0.78/gallon acid
Ion Exchange	$40,000/10 gpm	$6/1,000 gal sol'n
Membrane Electrolysis	$125,000/lb metal/d	$20/lb metal/d
Micro- and Ultra-filtration	$30,000/1 gpm	$25/day
Reverse Osmosis	$100,000/5 gpm	$40/day
Vacuum Evaporation	$150,000/1 gph	$0.15/gallon feed

lb = pound; d = day; gph = gallons per hour

[1]Source: Pollution Prevention and Control for Plating Operations, Cushnie, published by the National Center for Manufacturing Sciences, 1994.

5.2.4 Operation and Maintenance Requirements

The equipment needs to be scheduled to suit both system operations and maintenance. The technologies prefer continual operation (24-hours per day), at a steady flow rate. The systems face the greatest chance of degradation and damage during shutdowns. Pressure spikes and water hammer could make the membrane compact or surge piping and internal packing. Microbial growth and corrosion is more prominent during shutdown periods.

Generally, systems are sized to operate continually and are provided with 12 to 24 hours equalization residence time, to ensure uniform flow through the membrane system. Similarly, the discharge from the system goes to the holding tanks for inspection.

The systems are connected to the equalization tanks as either "feed and bleed" or once-through. "Feed and bleed" refers to the practice of using recirculation loops within the unit to maintain high cross-flow velocities and increased recovery. Microfiltration, ultrafiltration, and membrane electrolysis are commonly connected as feed and bleed. Diffusion dialysis, ion exchange, reverse osmosis and vacuum evaporation are commonly configured as once through systems.

The membrane materials are selected for their abilities to both perform the separation and withstand fouling. The pore size and the "molecular weight cutoff" (MWCO) are two important characteristics of the membrane. The wastewater characteristics that interact with the membrane surface are concentration, ionic strength, pH, temperature, and flowrate. In pressure-driven membrane processes, the design specification needs to consider each of these parameters.

Membranes and ion exchange resins generally give 2-10 years of service life, if operated properly. The following list summarizes key general O&M issues related to the recovery/reuse technology.

- Keep steady flow.
- Do not over pressurize membranes. (In particular, diffusion dialysis should not exceed over 2 psig).

- Keep solution temperature below 100ºF. Friction generated during membrane operation may generate heat, which would require auxiliary utility cooling.
- Arrange a cation bed before an anion bed. Pay attention to ion exchange regeneration instructions, in order to avoid damaging resin beads during regeneration.
- Choose cleaning and regenerant chemicals that are compatible with (do not precipitate or react with) the contaminant being cleaned from the process equipment.
- Once wet, keep membranes wet.
- Some membranes will require chemical treatment before storing.
- Install instrumentation and controls to the system equipment as necessary to monitor the process for operation and maintenance requirements.

In addition, selection of a recovery/reuse process should also consider the surface properties of the membrane. The materials of construction can be hydrophobic or hydrophilic and can also have a surface charge, all of which impact the performance of the membrane for specific applications.

Membranes are now available in a vast range of materials, from cellulosics to thermoplastics to ceramics to sintered metals. Each material has advantages and disadvantages that make it suitable for various applications. When selecting a membrane material, all of the above factors must be considered with each application having its own unique set of requirements. The traditional materials used in the fabrication of membranes include cellulose acetate, polyamide, and polysulfone. Other polymers are also used in the manufacture of membranes and include polypropylene, nylon, polyacrylonitrile (PAN), polycarbonate, polyvinyl alcohol (PVA), and polyvinylidene fluoride (PVDF). Furthermore, these materials can be subsequently coated to form thin-film composites (typically with polyamide or sulfonated polysulfone), which, in turn, impart ultrafilter membranes with nanofilter or reverse osmosis characteristics. In addition, ceramic and metallic membranes are used for MF and UF applications.

5.2.5 Purchasing information

Numerous vendors exist that can provide not only equipment, but also make equipment recommendations and provide technical support. It would be impossible to list all available vendors in this report. It is suggested that a search of the Internet be done to obtain a list of equipment vendors. For example, one such site www.waterinfocenter.com lists over 1000 vendors of water recovery and reuse equipments. This particular site is sponsored by *Water Engineering and Management*, *Water and Wastes Digest*, and *Water Quality Report* and is given as an example of the numerous websites that are available to provide vendor information.

5.3 Lessons Learned during Project Demonstrations

5.3.1 Demonstrations

Demonstrations were conducted at the three shipyards participating in the project. Three reports describing each of these demonstrations and the results is included in this manual as guidance to assist other shipyards in conducting demonstrations of their own. This information is located in Appendix D.

5.3.2 Cost Analysis

As part of the demonstration costs data was collected from each of the shipyards to determine implementation costs and savings for the recovery and reuse equipment. Data collected from each shipyard includes the following:

- Labor rate (burdened composite rate will suffice)
- Utility costs
- Existing disposal/recycling costs
- Materials
- Equipment
- Support costs

These costs were used to determine capital and operating costs. A comparison between present costs and those that would be realized after implementation of the recovery and reuse equipment was conducted. This data, although specific to individual shipyards, can assist other shipyards in determining the potential economic feasibility of recovery and reuse of their wastewater streams.

A cost analysis was complete on a sampling of the demonstrations; these were chosen to show how projects can vary, for example both economically feasible and not feasible projects. A summary of the costs analysis completed for this project is given below in Table 8. Additional detail on these analyses is given in Appendix E.

Table 8. Wastewater Recovery and Reuse Cost Analysis Summary

Description	Scenario	Capital Costs	Annual Costs	Annual Savings	P/B	NPV-15 [1]	IRR
Pipe Bending - Alkaline Cleaner: Ion Exchange	Baseline	NA	$32,400	NA	NA	NA	NA
	Alternative	$10,000	$31,500	$850	14.9 years	$600	4.5%
Compressor Flush: Microfiltration	Baseline	NA	$4,500	NA	NA	NA	NA
	Alternative	$14,000	$3,550	$950	NA	($700)	3.5%
Pipe Flush: Microfiltration	Baseline	NA	$285,000	NA	NA	NA	NA
	Alternative	$36,000	$74,650	$210,350	0.34 years	$1,200,000	304.7%
Steam Cleaning: Microfiltration	Baseline	NA	$93,600	NA	NA	NA	NA
	Alternative	$36,000	$27,500	$66,250	1.09 years	$367,500	$95.8%

Notes:
P/B = Simple Payback Period in years (a lower value is generally preferred)
NPV-15 = Net Present Value of costs incurred after 15 years
[1] Calculations based on real interest rate of 4.0% per OMB Circular A-94 [dated June 24, 1999; revised January 2000] to account for the time value of money and a aggregate tax rate of 48% was used.
Straight-line depreciation for a period of 15 years used for all calculations.
NA = Not Applicable
Parentheses indicate negative number

5.4 Facility Requirements

Facility requirements given here are based on the mobile wastewater treatment units used during this project. They are given as an indicator of what facility requirements may be required. However, actual vendor specifications for the intended equipment must be evaluated to determine the feasibility of implementation.

Utility connections to and from the mobile wastewater treatment units are designed such that the utilities can be quickly, safely, and easily connected to the required unit. All process connections for the mobile wastewater treatment units are Banjo quick connectors (100-A) (mating plug 100-B is provided). Cooling water connectors are Swagelok quick connectors. All electrical outlets are Hubbell connectors (Cat. No. 460R7W, mating plug 460P7W is provided). Power cord and E-stop interconnect cable lengths are each 20-feet long.

5.3.1 Diffusion Dialysis

The assembled size of the mobile diffusion dialysis unit is 86" wide x 48" long x 72" tall. The required utilities and process connections are provided in Table 9.

Table 9. Required Utilities for the Mobile Diffusion Dialysis Unit

Utility	Specifications
Waste acid inlet	Feed rate: 0.9 - 9.0 gph Temp: 10 - 85°C (52 – 185°F) Pressure: 30 psi max.
DI water inlet	Feed rate: 0.9 - 9.0 gph Temp: 10 - 40°C (52 - 105°F) Pressure: 30 psi max. Purity: 5 micro Siemens/cm
Reclaimed acid outlet	Flow rate: 0.9 - 9.0 gph
Reject metals outlet	Flow rate: 0.9 - 9.0 gph
Chilled water inlet	Flow rate: variable, 0.5 - 2 gpm Temp: approx. 4 - 9°C (38 – 48°F) Pressure: approx. 50 psi
Chilled water outlet	Flow rate: variable, 0.5 - 2 gpm Temp: approx. 13°C (58°F) max. Pressure: approx. 45 psi
Power	480 VAC, 3 phase, 20 A
Circuit breaker interrupt rating	18,000 A @ 600 VAC 25,000 A @ 480 VAC

5.3.2 Ion Exchange

The assembled size of the mobile ion exchange unit is 48" wide x 96" long x 72" tall. The required utilities and process connections are provided in Table 10.

Table 10. Required Utilities for the Mobile Ion Exchange Unit

Utility	Specifications
Process feed inlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.) Temp: 48°C (118°F) max. Pressure: 35 - 45 psi
Optional process inlet	
Process return outlet	
Acid feed inlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.) Temp: 10 - 23°C (52 - 75°F)
Cation regeneration waste outlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.)
Caustic feed inlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.) Temp: 10 - 23°C (52 - 75°F)
Anion regeneration waste outlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.)
Rinse water feed inlet	Flow rate: 0.5 - 1 gpm (2.2 gpm max.) Temp: 10 - 23°C (52 - 75°F)
Chilled water inlet	Temp: approx. 4 - 9°C (38 - 48°F)
Chilled water outlet	Temp: approx. 13°C (58°F)
Power	480 VAC, 3 phase, 20 A
Circuit breaker interrupt rating	18,000 A @ 600 VAC 25,000 A @ 480 VAC

5.3.3 Membrane Electrolysis

The assembled size of the mobile membrane electrolysis unit is 86" wide x 48" long x 78" tall. The required utilities and process connections are provided in Table 11.

Table 11. Required Utilities for the Mobile Membrane Electrolysis Unit

Utility	Specifications
Anolyte inlet	Feed rate: 0.5 - 2 gpm Temp: 10 - 85°C (52 - 185°F)
Catholyte inlet	Feed rate: 0.5 - 2 gpm Temp: 10 - 85°C (52 - 185°F)
Process inlet	Feed rate: 0.5 - 2 gpm Temp: 10 - 85°C (52 - 185°F)
Anolyte outlet	Feed rate: 0.5 - 2 gpm
Catholyte outlet	Feed rate: 0.5 - 2 gpm
Process outlet	Feed rate: 0.5 - 2 gpm
City water inlet	Approx. 13°C (55°F)
City water outlet	Approx. 18°C (65°F)
Electrical cabinet cooling water inlet	Approx. 4 - 9°C (38 - 48°F)
Electrical cabinet cooling water outlet	Approx. 13°C (55°F)
Power process components electrical components	480 VAC, 3 phase approx. 7.5 kW rectifier 3 kW, transformer 6 kW

5.3.4 Micro/Ultrafiltration

The assembled size of the mobile micro/ultrafiltration unit is 48" wide x 96" long x 78" tall. The required utilities and process connections are provided in Table 12.

Table 12. Required Utilities for the Mobile Micro/Ultrafiltration Unit

Utility	Specifications
Chilled water inlet	Temp: approx. 4 - 9°C (38 - 48°F)
Chilled water outlet	Temp: approx. 13°C (58°F) max.
Main feed inlet	6 gpm max.
Process outlet permeate	0.1 to 2.4 gpm
Compressed air	Min. 20 cfm @ 85 psi
Power	480 VAC, 3 phase, 20 A
Circuit breaker interrupt rating	18,000 A @ 600 VAC 25,000 A @ 480 VAC

5.3.5 Reverse Osmosis

The assembled size of the mobile reverse osmosis unit is 48" wide x 86" long x 72" tall. The required utilities and process connections are provided in Table 13.

Table 13. Required Utilities for the Mobile Reverse Osmosis Unit

Utility	Specifications
Main feed inlet	Min. Temp: 8°C (45°F) Max. Temp: 38°C (100°F)
Permeate outlet	
Concentrate outlet	
Chilled water inlet	4 - 9°C (38 - 48°F)
Chilled water outlet	Approx. 13°C (58°F) max.
Compressed air or nitrogen (required for pressurizing the compression tank before starting the system)	Charge of 250 - 550 psi (dependent on desired operating pressure).
Power	480 VAC, 3 phase, 20 A
Circuit breaker interrupt rating	18,000 A @ 600 VAC 25,000 A @ 480 VAC

5.3.6 Vacuum Evaporation

The vacuum evaporator is not a mobile unit. Therefore required utilities would vary based on the size of equipment. Contact a appropriate vendor to obtain this information.

6.0 REGULATORY COMPLIANCE ISSUES

When considering the feasibility of recovery and reuse of process wastewater discharges at ship building and repair sites, one must keep in mind two environmental laws, the Resource Conservation and Recovery Act (RCRA) and the Clean Water Act (CWA), and their associated regulations. The issues regarding these two laws as they apply to the shipbuilding and repair industry are outlined below.

6.1 Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) of 1976, which amended the Solid Waste Disposal Act, addresses solid (Subtitle D) and hazardous (Subtitle C) waste management activities.

Regulations promulgated pursuant to Subtitle C of RCRA (40 CFR Parts 260-299) establish a "cradle-to-grave" system governing hazardous waste from the point of generation to disposal. RCRA hazardous wastes include the specific materials listed in the regulations (commercial chemical products, designated with the code "P" or "U"; hazardous wastes from specific industries/sources, designated with the code "K"; or hazardous wastes from non-specific sources, designated with the code "F") or materials which exhibit a hazardous waste characteristic (ignitability, corrosivity, reactivity, or toxicity and designated with the code "D").

Regulated entities that generate hazardous waste are subject to waste accumulation, manifesting, and record keeping standards. Facilities must obtain a permit either from

EPA or from a state agency, which the U.S. EPA has authorized to implement the permitting program, if they store hazardous wastes for more than 90 days (or 180 days depending on the amount of waste generated) before treatment or disposal. Facilities may treat hazardous wastes stored in less-than-ninety-day tanks or containers without a permit provided the procedure is approved by a state agency having RCRA delegation authority. Subtitle C permits contain general facility standards such as contingency plans, emergency procedures, record keeping and reporting requirements, financial assurance mechanisms, and unit-specific standards.

Although RCRA is a Federal statute, most states implement the RCRA program. Currently, EPA has delegated its authority to implement various provisions of RCRA to every state except Alaska, Hawaii, and Iowa. Most RCRA requirements are not industry specific but apply to any company that generates, transports, treats, stores, or disposes of hazardous waste.

The regulations at 40 CFR Part 261 outline the procedure every generator must follow to determine whether the material in question is considered a hazardous waste, solid waste, or is exempted from regulation.

A material is classified under RCRA as a hazardous waste if the material meets the definition of solid waste (40 CFR 261.2), and that solid waste material exhibits one of the characteristics of a hazardous waste (40 CFR 261.20-40) or is specifically listed as a hazardous waste (40 CFR 261.31-33). A material defined as a hazardous waste may then be subject to Subtitle C generator (40 CFR 262), transporter (40 CFR 263), and treatment, storage, and disposal facility (40 CFR 264 and 265) requirements. The shipbuilding and repair industry must be concerned with the regulations addressing all of these.

Several common shipyard operations have the potential to generate RCRA hazardous wastes. Some of these wastes are identified below by process.

Table 14. Potential RCRA Hazardous Waste

Process	Associated Waste
Machining and Other Metalworking	Metalworking fluids contaminated with oils, phenols, creosol, alkalies, phosphorus compounds, and chlorine
Cleaning and Degreasing	Solvents (F001, F002, F003, F004, F005)
	Alkaline and Acid Cleaning Solutions (D002)
	Cleaning filter sludges with toxic metal concentrations
Metal Plating and Surface Finishing and Preparation	Wastewater treatment sludges from electroplating operations (F006)
	Spent cyanide plating bath solutions (F007)
	Plating bath residues from the bottom of cyanide plating baths (F008)
	Spent stripping and cleaning bath solutions from cyanide plating operations (F009)
Surface Preparation, Painting and Coating	Paint and paint cans containing paint sludges with solvents or toxic metals concentrations
	Solvents (F002, F003)
	Paint chips with toxic metal concentrations
	Blasting media contaminated with paint chips
Vessel Cleaning	Vessel sludges
	Vessel cleaning wastewater
	Vessel cleaning wastewater sludges

While the shipbuilding and repair industry must be familiar with all aspects of RCRA, to determine whether a material meets the definition of solid waste is the key to RCRA and is always the starting point for RCRA analyses, including those addressing the regulatory status of recyclable materials.

6.1.1 Definition of Solid Waste

EPA's RCRA regulations define a "solid waste" as "any discarded material that is not excluded by §261.4(a) or that is not excluded by a variance granted under §§260.30 and 260.31." A "discarded material" is defined as one that is "abandoned," "inherently waste-like," or "recycled" in defined ways. Each of these terms has a specific regulatory definition. Materials are "abandoned" if they are disposed of, burned or incinerated, or accumulated, stored, or treated (but not recycled) before or in lieu of being abandoned. In other words, a material is considered abandoned, and thus discarded, if it is thrown away. "Inherently waste-like" materials are hazardous regardless of how they are managed. These materials include listed hazardous wastes F020, F021 (unless used as an ingredient to make a product at the site of generation), F022, F023, F026, and F028; hazardous materials that are fed to a halogen acid furnace (except for certain brominated material); and any other material specifically listed by EPA using the criteria set forth at section 261.2(d)(3).

It is important to note that materials that are recycled can also be deemed discarded. A material is "recycled" if it is used, reused, or reclaimed. A material is "used or reused" if it is either: (i) Employed as an ingredient (including use as an intermediate) in an industrial process to make a product. However, a material will not satisfy this condition if distinct components of the material are recovered as separate end products; or (ii) Employed in a particular function or application as an effective substitute for a commercial product.

A material is "reclaimed" if it is "processed to recover as a usable product, or if it is regenerated (e.g., recovery of lead from spent batteries and regeneration of spent solvents).

Some materials that are recycled are classified as solid wastes, while others are exempt from regulation. Whether a material is considered to be a solid waste when recycled depends upon two criteria: (1) what type of secondary material is being recycled; and (2) the manner in which the material is recycled.

The term "secondary material" is used primarily within the context of RCRA recycling. It is not defined in the federal regulations, but generally means "any materials that potentially can be solid and hazardous wastes when recycled." See 50 Fed. Reg. 616 (January 4, 1985). All secondary materials fit into one of the seven categories listed below.

Section 261.2(c) sets forth the seven types of secondary materials:

(1) spent materials;
(2) sludges that are specifically listed as a hazardous waste;
(3) sludges that exhibit a hazardous characteristic;
(4) by-products that are listed as hazardous wastes;
(5) by-products that are characteristically hazardous;
(6) commercial chemical products that are listed as hazardous wastes; and
(7) scrap metal that is not excluded from regulation.

A "spent" material is defined as any material that has been used and as a result of contamination can no longer serve the purpose for which it was produced without reprocessing. Examples of spent materials include, spent solvents, spent blast abrasives, spent acids, and spent lubricating oils.

A "sludge" is any solid, semi-solid, or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility, exclusive of the treated effluent from a wastewater treatment plant. An example is emission control dust collected in a baghouse hopper.

According to section 261.1(c)(3), a "by-product" is a material that is not one of the primary products of a production process and is not solely or separately produced by the production process. Examples include process residuals such as slags and distillation column bottoms. The term does not include co-products that are produced for the general public's use and are ordinarily used in the form that is produced by the process. The term "by-products" is intended to capture wastes that do not meet the definition of spent materials or sludges.

"Commercial chemical products" ("CCPs") include discarded chemical products, off-specification species, container residues, and spill residues of commercial chemical products specifically listed at 40 C.F.R. § 261.33. CCPs make up the P- and U-listed wastes. An example of a CCP is unused or off-specification methyl ethyl ketone (MEK).

Once the type of material being recycled is known, the manner is which it is recycled is determinative of whether it is regulated as a solid waste and, thus, potentially as a hazardous waste. EPA currently recognizes four general categories of recycling: (1) use constituting disposal; (2) burning for energy recovery; (3) reclamation; and (4) speculative accumulation. Each of these recycling activities is briefly described below.

A product is said to be "used in a manner constituting disposal" if it, or a product derived from that material, is used or placed directly on the land. An exception to this general rule is commercial chemical products that are placed on the land, provided that such land use is consistent with the product's normal use (e.g., pesticides). With this one exception, secondary materials that are used in a manner constituting disposal are regulated as solid and potentially hazardous wastes. However, certain hazardous recyclable materials that are produced for the general public's use are not currently subject to regulation as hazardous wastes.

As stated above, a secondary material is reclaimed if it is processed to recover a usable product (e.g., recovery of lead values from batteries) or regenerated (e.g., regeneration of spent solvents). Characteristically hazardous sludges, by-products, and commercial chemical products are not solid wastes when reclaimed. Other secondary materials that are reclaimed, however, are solid wastes.

All secondary materials, except commercial chemical products, that are speculatively accumulated prior to recycling are solid wastes. "Speculative accumulation" is defined by what it is not. A material is not "speculatively accumulated" if the person accumulating the material can show: (1) that the material is potentially recyclable; (2) there is a feasible means of recycling the material; and (3) that during the calendar year (commencing on January 1), the amount of material that is recycled, or transferred to a different site for recycling, equals at least 75 percent by weight or volume of the amount of that material accumulated at the beginning of the period. The 75 percent requirement is applied to each material of the same type that is recycled in the same way.

6.1.2 Exclusions Under 40 CFR §261.2(e)(1)

In addition to characteristic sludges and by-products, and commercial chemical products that are reclaimed, secondary materials that can be used as ingredients to produce another product or that can effectively replace another product are excluded from regulation provided that certain conditions are met. Wastes recycled in this manner are not considered to be discarded, and are thus not subject to regulation as hazardous wastes. Specifically, section 261.2(e)(1) excludes from the definition of solid waste materials that can be shown to be recycled by being:

(i) used or reused as ingredients in an industrial process to make a product, provided the materials are not being reclaimed;
(ii) used or reused as effective substitutes for commercial products; or
(iii) returned to the original process from which they are generated, without first being reclaimed or land disposed. The materials must be returned as a substitute for feedstock materials. In cases where the original process to which the materials are returned is a secondary process, the materials must be managed such that there is no placement on the land.

To qualify for one of the above exemptions, the recycler must demonstrate that conditions of the particular exclusion are met (e.g., the material is an ingredient, an effective substitute, or returned to the original process from which it was generated, without first being reclaimed). The recycler must also satisfy an implied criterion, namely, that the recycling activity is "legitimate" and not a form of waste treatment or "sham" recycling. EPA has established criteria for evaluating whether a particular recycling activity is legitimate and not a sham. Not one factor is determinative, but rather all of the criteria are balanced.

6.1.3 Other Exclusions from the Definition of Solid Wastes

In addition to the regulatory exclusion for secondary materials under section 261.2(e)(1) (use or reuse without first being reclaimed), 12 other categories of materials are also specifically exempt from the definition of solid waste under section 261.4. Of these, only three are of any potential importance to the shipyard industry. The other exempted materials are specific to other industry sectors. The three categories of exempt materials that are potentially relevant to shipyards are:

(1) Industrial wastewater discharges that are point source discharges subject to regulation under section 402 of the Clean Water Act, as amended;
(2) Spent sulfuric acid used to produce virgin sulfuric acid, unless it is accumulated speculatively; and
(3) Secondary materials that are reclaimed and returned to the original process or processes in which they were generated where they are reused in the production process provided: (i) only tank storage is

involved and the entire process is closed by being entirely connected by pipes or other comparable means of conveyance; (ii) reclamation does not involve controlled flame combustion; (iii) the secondary materials are never accumulated in such tanks for more than 12 months without being reclaimed; and (iv) the reclaimed material is not used to produce a fuel, or used to produce products that are used in a manner constituting disposal.

The last exemption cited above is known as the "closed-loop" exemption and is widely used by industry. It is this exemption that may be most beneficial to shipyards using wastewater recovery and regeneration systems to decrease waste and process wastewater discharges.

If the secondary material is excluded or exempt for the definition of solid waste, the RCRA recycling analysis is over, and the material can be recycled without limitation. If a secondary material is deemed to be a solid waste, the next step in the process is to determine if the waste meets the definition of hazardous waste.

6.1.4 Regulation of Hazardous Wastes

Under EPA's regulatory definition, which is set forth at 40 C.F.R. § 261.3, unless specifically exempted or excluded, a solid waste is hazardous if: (1) it is specifically listed as a hazardous waste (i.e., F-, K-, P-, and U-listed wastes (see § 261.33)); or (2) it exhibits one or more of the following hazardous characteristics: ignitability, corrosivity, reactivity, or toxicity (see §261.21-24). Included in the definition of hazardous wastes are mixtures of a listed waste and a solid waste, and mixtures of characteristic wastes and solid wastes that exhibit a hazardous characteristic after being mixed. Also included are solid wastes derived from the treatment, storage, and disposal of listed wastes and characteristically hazardous wastes derived from the treatment, storage, and disposal of characteristically hazardous wastes and mixtures.

Solid wastes that are neither specifically listed as hazardous wastes nor exhibit a hazardous characteristic are not regulated under RCRA Subtitle C. Solid wastes that are hazardous are subject to varying degrees to Subtitle C, unless specifically excluded or exempted from regulation.

Hazardous wastes that are recycled are known as "recyclable materials." When a material is classified as a solid waste because it is recycled [and does not qualify for a use/reuse exclusion under section 261.2(e)] and it meets the definition of hazardous waste, sections 261.6 and 261.9 are used to determine the level of regulation placed on the waste and the recycling activity. These standards range from no regulation to full regulation, depending on the type and manner of recycling. The recycling unit itself is not subject to regulation; nor necessarily is the product of the recycling activity.

The regulatory status of recycled (i.e., reclaimed) wastes is frequently misunderstood. Many onsite recyclers believe that wastes (such as spent solvents) that are recycled are not

RCRA wastes subject to regulation. This is typically not the case. Unless specifically excluded, wastes that are recycled by being reclaimed are RCRA solid wastes, and hazardous wastes if they meet a listing description, or if they exhibit a hazardous characteristic. Thus, hazardous wastes recycled using any of the recycling techniques described earlier, with the exception of those directly used or reused, are regulated as "recyclable materials," and must be managed as such prior to and during recycling.

Although reclamation of wastes is a form of "treatment," shipyards are not required to obtain a RCRA storage or treatment permit provided that they comply with RCRA's generator requirements. In particular, prior to being recycled, wastes must be stored in RCRA tanks or containers and must be recycled or sent offsite for treatment or disposal within 90 days of the date they were generated. EPA interprets section 262.34 (generator accumulation provision) as exempting from RCRA permitting requirements generators that treat their own wastes during the generator 90-day accumulation period in RCRA tanks or containers. Shipyards that fail to adhere to these requirements are, by operation of law, potentially subject to regulation as RCRA Treatment, Storage and Disposal (TSD) facilities.

Although wastes being reclaimed are regulated as hazardous wastes, the actual recycling unit itself and the reclaimed material are not subject to regulation. Once reclaimed, the material can be used and stored in the same manner as other virgin materials. Residues generated from the reclamation activity remain subject to regulation. If the waste being reclaimed is a listed waste (F001-F005), the waste residue must continue to be regulated as a listed waste. If the reclaimed waste was characteristically hazardous, the residue must be managed as hazardous only if it exhibits a hazardous characteristic. The recycling unit is a distinct point of generation. Thus, for generator accumulation purposes, the 90-day clock does not start ticking until the waste residues exit the recycling unit (not the date that the waste was first generated).

While the above discussion addresses only federal waste regulations, shipyards must also be aware of associated state and local waste regulations that may impact their operations. These state and local regulations may be more stringent than their federal counterparts and may go so far as to eliminate particular exemptions that the shipyard planned to invoke. It is therefore essential for shipyards to thoroughly assess all applicable state and local regulations and fully comprehend their impact.

6.1.4.1 United States Code, Title 10, Section 7311

Title 10, Section 7311 of the U.S. Code applies specifically to the handling of hazardous waste (as defined by RCRA) during the repair and maintenance of naval vessels. Section 7311 requires the navy to identify the types and amounts of hazardous wastes that will be generated or removed by a contractor working on a naval vessel and that the navy compensate the contractor for the removal, handling, storage, transportation, or disposal of the hazardous waste. The Code also requires that waste generated solely by the navy and handled by the contractor bears a generator identification number issued to the navy; wastes generated and handled solely by the contractor bears a generator identification number issued to the contractor; and waste generated by both the navy and the contractor and handled by the contractor bears a generator identification number issued to the contractor and a generator identification number issued to the navy.

6.2 Clean Water Act

Pollutants regulated under the CWA include "priority" pollutants, including various toxic pollutants; "conventional" pollutants, such as biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform, oil and grease, and pH; and "non-conventional" pollutants, including any pollutant not identified as either conventional or priority. The CWA regulates both direct and indirect discharges.

6.2.1 Direct Discharges

The National Pollutant Discharge Elimination System (NPDES) program (CWA §502) controls direct discharges into navigable waters. NPDES permits, issued by either EPA or an authorized state (EPA has authorized 42 states to administer the NPDES program), contain industry-specific, technology-based and/or water quality-based limits, and establish pollutant monitoring requirements. A facility that intends to discharge into the nation's waters must obtain a permit prior to initiating its discharge. A permit applicant must provide quantitative analytical data identifying the types of pollutants present in the facility's effluent. The permit will then set the conditions and effluent limitations on the facility discharges.

A NPDES permit may also include discharge limits based on federal or state water quality criteria or standards, that were designed to protect designated uses of surface waters, such as supporting aquatic life or recreation. These standards, unlike the technological standards, generally do not take into account technological feasibility or costs. Water quality criteria and standards vary from state to state, and site to site, depending on the use classification of the receiving body of water. Most states follow EPA guidelines that propose aquatic life and human health criteria for many of the 126 priority pollutants.

6.2.2 Pretreatment Program

Another type of discharge that is regulated by the CWA is one that goes to a publicly-owned treatment works (POTW). The national pretreatment program (CWA §307(b)) controls the indirect discharge of pollutants to POTWs by "industrial users." Facilities regulated under §307(b) must meet certain pretreatment standards. The goal of the pretreatment program is to protect municipal wastewater treatment plants from damage that may occur when hazardous, toxic, or other wastes are discharged into a sewer system and to protect the quality of sludge generated by these plants. EPA has developed technology-based standards for industrial users of POTWs. Different standards apply to existing and new sources within each category. "Categorical" pretreatment standards applicable to an industry on a nationwide basis are also developed by EPA.

However, discharges to a POTW are regulated primarily by the POTW, rather than the state or EPA. To ensure that the POTW achieves the effluent limitations in its NPDES permit, the POTW develops another kind of pretreatment standard referred to as "local limits." As these local limits are nearly always stricter than state or federal standards, they are critical to a shipyard's compliance efforts. Shipyards must be fully cognizant of the local limits that apply to their various wastestreams and must ensure that their discharges to the POTW do not exceed these limits. It is imperative that these local standards not be overlooked. Finally, keep in mind that regardless of whether a state is authorized to implement either the NPDES or the pretreatment program, if it develops its own program, it may enforce requirements more stringent than federal standards.

Shipbuilding and repair facility wastewater released to surface waters is regulated under the CWA. National Pollutant Discharge Elimination System (NPDES) permits must be obtained to discharge wastewater into navigable waters (40 Part 122). Facilities that discharge to a POTW may be required to meet National Pretreatment Standards for some contaminants. General pretreatment standards applying to most industries discharging to a POTW are described in 40 CFR Part 403. In addition, effluent limitation guidelines, new source performance standards, pretreatment standards for new sources, and pretreatment standards for existing sources may apply to some shipbuilding and repair facilities that carryout electroplating or metal finishing operations. Requirements for the Electroplating Point Source Category and the Metal Finishing Point Source Category are listed under 40 CFR Part 413 and 40 CFR Part 433, respectively.

6.2.3 Storm Water Discharges

In 1987 the CWA was amended to require EPA to establish a program to address storm water discharges. In response, EPA promulgated the NPDES storm water permit application regulations. These regulations require that facilities with the following storm water discharges apply for an NPDES permit: (1) a discharge associated with industrial activity; (2) a discharge from a large or medium municipal storm sewer system; or (3) a discharge which EPA or the state determines to contribute to a violation of a water quality standard or is a significant contributor of pollutants to waters of the United States.

The term "storm water discharge associated with industrial activity" means a storm water discharge from one of 11 categories of industrial activity defined at 40 CFR 122.26. Six of the categories are defined by SIC codes while the other five are identified through narrative descriptions of the regulated industrial activity. If the primary SIC code of the facility is one of those identified in the regulations, the facility is subject to the storm water permit application requirements. If any activity at a facility is covered by one of the five narrative categories, storm water discharges from those areas where the activities occur are subject to storm water discharge permit application requirements.

Many shipbuilding and repair facilities fall within these categories. In particular, shipyards are likely to fall into Category ii, which is reproduced below:

<u>*Category ii*</u>*: Facilities classified as SIC 24-lumber and wood products (except wood kitchen cabinets); SIC 26-paper and allied products (except paperboard containers and products); SIC 28-chemicals and allied products (except drugs and paints); SIC 291-*

petroleum refining; and SIC 311-leather tanning and finishing, 32 (except 323)-stone, clay, glass, and concrete, 33-primary metals, 3441-fabricated structural metal, and ***373-ship and boat building and repairing****.*

Required treatment of storm water flows are expected to remove a large fraction of both conventional pollutants, such as total suspended solids (TSS) and biochemical oxygen demand (BOD), as well as toxic pollutants, such as certain metals and organic compounds.

6.3 Pending and Proposed Regulatory Requirements

6.3.1 Clean Water Act

New, stricter standards are on the horizon. In May 1995, EPA proposed effluent guidelines, new source performance standards, and pretreatment standards for wastewater discharges from certain facilities in a new industry category, Metal Products and Machinery (MP&M) (60 Fed. Reg. 28209, May 30, 1995). The new MP&M category would apply to new and existing facilities that manufacture, maintain, or rebuild finished metal parts, products, or machines for use in one of 15 industrial sectors (including the shipbuilding and repair industry). Originally planned in two phases, the MP&M Phase I standards proposed in May 1995 have subsequently been withdrawn. Phases I and II have now been combined and will be promulgated together according to the following schedule:

- Proposed MP&M rule - October 2000
- Final MP&M rule - December 2002

For further information on the status of the MP&M regulations, contact Steven Geil, U.S. EPA, Office of Water, Engineering and Analysis Division, (202) 260-9817, email: geil.steve@epamail.epa.gov).

APPENDIX A

Facility Descriptions

FACILITY DESCRIPTIONS

Three shipyards participated with *CTC* to conduct this project. A brief description of each of the three shipyards, Avondale, BIW, and NASSCO, is given below. The information for this section was obtained from their respective websites.

Avondale

Avondale Shipyards Division is part of Avondale Industries which serve marine, transportation, energy, defense, and industrial customers. The Shipyards Division, is located on the Mississippi River twelve miles upriver from the Port of New Orleans. This division manufactures primarily oceangoing vessels for both military and commercial markets. In addition, Avondale also repairs and performs modernizations of ships. Vessel classifications include U.S. Navy amphibious assault ships, fleet support ships, surface combatants, Coast Guard icebreakers and cutters, product and chemical carriers, lighter aboard ships (LASH vessels), and dredges.

Bath Iron Works Corporation (BIW)

BIW, a division of General Dynamics, is a manufacturer of surface combatants and provides world-class engineering and design services. BIW utilizes modular construction techniques to build these complex and sophisticated surface combatants for the U.S. Navy. These combatants include:

- DDG 51 Arleigh Burke Class AEGIS Destroyers
- LPD-17 Class - Amphibious Assault Ships
- DD-21 The Next Generation Surface Combatant.

National Steel and Shipbuilding Company (NASSCO)

NASSCO is a ship design, construction, and repair company located in San Diego, California, and is among the largest shipyards in the United States. The company employs a work force of about 5,000 people at its industrial facility encompassing 147 acres. NASSCO is organized to focus its management, technical, and shipyard resources on three major business areas:

- New ship design and construction
- Ship conversion and repair
- Industrial fabrication.

NASSCO constructs and converts both U.S. Navy and commercial ships, with both sectors providing approximately 50 percent of their business. In all, 296 ships, have been constructed or converted at their facility on the San Diego Bay so far. In addition, about 25 percent of NASSCO's business is devoted to the repair and overhaul of the U.S. Navy's Pacific Fleet in addition to both foreign and domestic commercial traders and cruise ships.

APPENDIX B

Shipyard Wastewater Discharge Survey

Report Number 1

Shipyard Wastewater Discharge Survey

October 15, 1998

“Prepared under Purchase Order Number MU322646-D"
for
National Steel & Shipbuilding Company (NASSCO)”

Prepared by:

Concurrent Technologies Corporation
100 *CTC* Drive
Johnstown, PA 15904

SHIPYARD WASTEWATER DISCHARGE SURVEY

This survey form was prepared by Concurrent Technology Corporation (*CTC*) in support of a National Shipbuilding Research Program (NSRP) project to demonstrate wastewater treatment technologies at various shipyards. This survey is modeled after the Environmental Protection Agency's MP&M Phase II Survey since similar information is needed for this project. The information gathered using these surveys will be used to identify, prioritize, and select target wastewater streams at each shipyard for treatment using *CTC*'s mobile wastewater treatment units. Therefore, it is important that all information provided is as accurate and complete as possible.

The first part of the survey requests general shipyard information. The survey progressively gets more detailed and specific as it asks for information at the process level and finally at the unit operation level.

In addition to this survey form, CTC requests copies of site plans or other documentation showing the major process areas and utilities (water and power). This will be useful information for planning the installation and utility connections for the mobile wastewater treatment units.

Some sections of this survey may require multiple copies of the same page to complete all information requested. Upon completion of the entire survey, please number each page at the top right hand corner. Reference and attach supporting documentation as applicable.

ACRONYMS

CFR	Code of Federal Regulations
CTW	Combined Treatment Works
EPA	Environmental Protection Agency
FOTW	Federally-Owned Treatment Works
NPDES	National Pollution Discharge Elimination System
POC	Point of Contact
POTW	Publicly-Owned Treatment Works
PrOTW	Privately-Owned Treatment Works
TS	Treatment System
UO	Unit Operation

SHIPYARD WASTEWATER DISCHARGE SURVEY

***CTC* POC:** ______________________________ **Date:** ____________________

Phone: ______________________________

SHIPYARD INFORMATION

Site Name:

____

____

____

Address:

____

____

____

Primary POC

Name: ______________________________

Title: ______________________________

Phone: ______________________________

Fax: ______________________________

Email: ______________________________

Secondary POC

Name: ______________________________

Title: ______________________________

Phone: ______________________________

Fax: ______________________________

Email: ______________________________

CHARACTERIZATION OF SHIPYARD ACTIVITIES

Brief Description of Product(s)	Annual Quantity Processed (include units of measure)	Shipyard Activities Associated with Product(s)
		❑ Manufacturing ❑ Rebuilding/Maintenance
		❑ Manufacturing ❑ Rebuilding/Maintenance
		❑ Manufacturing ❑ Rebuilding/Maintenance
		❑ Manufacturing ❑ Rebuilding/Maintenance
		❑ Manufacturing ❑ Rebuilding/Maintenance
		❑ Manufacturing ❑ Rebuilding/Maintenance

PROCESS WASTEWATER

Does your site discharge process wastewater? ❑ Yes ❑ No

Process wastewater, as defined by the EPA, is any water that, during manufacturing, rebuilding, or maintenance comes into direct contact with, or is generated from, the production or use of any raw materials, intermediate product, finished product, by-product, or waste product. Sanitary and non-contact cooling water are not considered process wastewater. Wastewater from air pollution control devices, painting or metal spraying water curtains, water-soluble coolants, and rinse water is considered process wastewater. Process wastewater may also include wastewater that is contract hauled off-site for disposal.

Is process wastewater discharged to off-site treatment works? ❑ Yes ❑ No

If yes, what type? ❑ POTW ❑ PrOTW ❑ FOTW ❑ CTW ❑ Other ________

Name and address of treatment works:

____

____

____

Phone Number: ______________________________

Permit number (if applicable):

____

Is process wastewater discharged to surface water? ❑ Yes ❑ No

Name and type of receiving water: ____

NPDES Permit No.: ________________________

Is process wastewater discharged to other destinations?

❑ Holding pond ❑ Deep-well injection ❑ Contract hauled ❑ Septic system ❑ Other ________

Is your site regulated under one or more existing federal categorical effluent limitations guidelines?

❑ Yes (please check all that apply) ❑ No

- ❑ Electroplating, 40 CFR 413
- ❑ Metal Finishing, 40 CFR 433
- ❑ Metal Molding and Casting, 40 CFR 464
- ❑ Nonferrous Metals Forming and Metal Powders, 40 CFR 471
- ❑ Plastics Molding and Forming, 40 CFR 466
- ❑ Other ____________________

Are effluent concentration limits for your site water quality-based?

❑ Yes ❑ No ❑ Unknown

PROCESS INFORMATION

Unit Operation ID#	Name	Operation is performed dry (✓)	Operation is performed using water(1)(✓)	Operation has one or more associated rinses (✓)	Process wastewater discharged from this operation(2)	Process wastewater discharged from associated rinse for this operation
UO-1	Abrasive Blasting				gal/yr	gal/yr
UO-2	Abrasive Jet Machining				gal/yr	gal/yr
UO-3	Acid Treatment with Chromium				gal/yr	gal/yr
UO-4	Acid Treatment without Chromium				gal/yr	gal/yr
UO-5	Alkaline Cleaning for Oil Removal				gal/yr	gal/yr
UO-6	Alkaline Treatment with Cyanide				gal/yr	gal/yr
UO-7	Alkaline Treatment without Cyanide				gal/yr	gal/yr
UO-8	Anodizing with Chromium				gal/yr	gal/yr
UO-9	Anodizing without Chromium				gal/yr	gal/yr
UO-10	Aqueous Degreasing				gal/yr	gal/yr
UO-11	Assembly/Disassembly				gal/yr	gal/yr
UO-12	Barrel Finishing				gal/yr	gal/yr
UO-13	Burnishing				gal/yr	gal/yr
UO-14	Chemical Conversion Coating (non chrome)				gal/yr	gal/yr
UO-15	Chemical Milling/Machining				gal/yr	gal/yr
UO-16	Chromate Conversion Coating				gal/yr	gal/yr
UO-17	Corrosion Preventive Coating				gal/yr	gal/yr
UO-18	Electrical Discharge Machining				gal/yr	gal/yr
UO-19	Electrochemical Machining				gal/yr	gal/yr
UO-20	Electroless Plating				gal/yr	gal/yr
UO-21	Electrolytic Cleaning				gal/yr	gal/yr
UO-22	Electroplating with Chromium				gal/yr	gal/yr
UO-23	Electroplating with Cyanide				gal/yr	gal/yr
UO-24	Electroplating (non Chromium or Cyanide)				gal/yr	gal/yr
UO-25	Electropolishing				gal/yr	gal/yr
				Subtotal	gal/yr	gal/yr

(1) Other than non-contact cooling water

(2) Excluding rinse water

PROCESS INFORMATION (cont.)

Unit Operation ID#	Name	Operation is performed dry (✓)	Operation is performed using water[1] (✓)	Operation has one or more associated rinses (✓)	Process wastewater discharged from this operation[2]	Process wastewater discharged from associated rinse for this operation
UO-26	Floor Cleaning (in process area)				gal/yr	gal/yr
UO-27	Grinding				gal/yr	gal/yr
UO-28	Heat Treating				gal/yr	gal/yr
UO-29	Impact Deformation				gal/yr	gal/yr
UO-30	Machining				gal/yr	gal/yr
UO-31	Metal Spraying (incl. water curtain)				gal/yr	gal/yr
UO-32	Painting – Spray/Brush (incl. water curtain)				gal/yr	gal/yr
UO-33	Painting – Immersion (incl. E-coat)				gal/yr	gal/yr
UO-34	Plasma Arc Machining				gal/yr	gal/yr
UO-35	Polishing				gal/yr	gal/yr
UO-36	Pressure Deformation				gal/yr	gal/yr
UO-37	Salt Bath Descaling				gal/yr	gal/yr
UO-38	Soldering/Brazing				gal/yr	gal/yr
UO-39	Solvent Degreasing				gal/yr	gal/yr
UO-40	Stripping (paint)				gal/yr	gal/yr
UO-41	Stripping (metallic coating)				gal/yr	gal/yr
UO-42	Testing				gal/yr	gal/yr
UO-43	Thermal Cutting				gal/yr	gal/yr
UO-44	Washing (finished products)				gal/yr	gal/yr
UO-45	Welding				gal/yr	gal/yr
UO-46	Wet Air Pollution Control				gal/yr	gal/yr
UO-47	Other (specify):				gal/yr	gal/yr
UO-48	Other (specify):				gal/yr	gal/yr
				Subtotal	gal/yr	gal/yr
				Subtotal from previous page	gal/yr	gal/yr
				Total	gal/yr	gal/yr
				Total combined process wastewater and rinse water discharge		gal/yr

(1) Other than non-contact cooling water

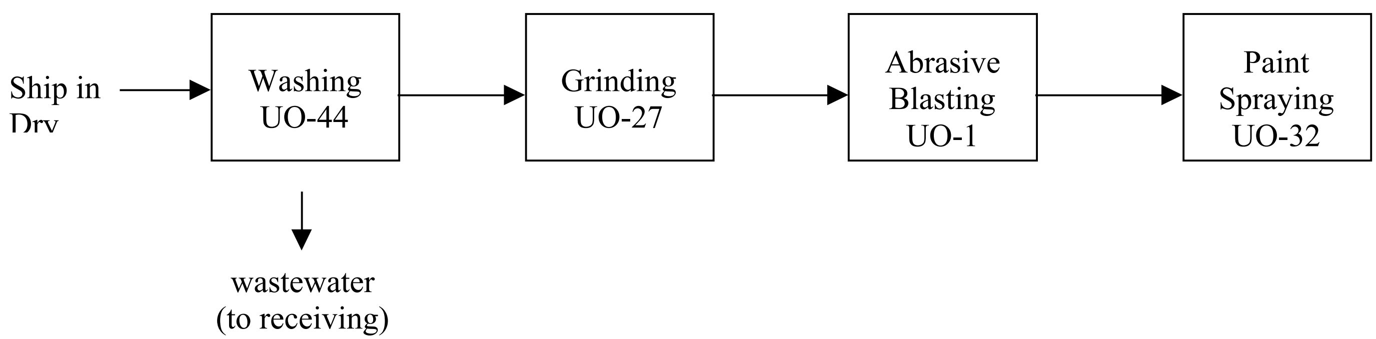
(2) Excluding rinse water

PROCESS FLOW DIAGRAMS

Attach a process block diagram illustrating the sequence in which all manufacturing, rebuilding, and maintenance operations are conducted. Include blocks for operations that do not use water. Specify the unit operation ID# from the PROCESS INFORMATION tables. Indicate the destination of all water used in a process (e.g., used in another process, discharged to treatment, discharged without treatment, or contract hauled).

EXAMPLE:

Process # <u> EX </u> **:** <u>Exterior Hull Prep</u> (name) **POC:** <u>J. Smith, Lead Engineer</u> **Phone:** <u>(123) 456-7890</u>



PROCESS FLOW DIAGRAMS (cont.)

Process #___: ____________________________________ POC: ______________________________ Phone: ______________________
(name)

Process #___: ____________________________________ POC: ______________________________ Phone: ______________________
(name)

PROCESS WASTEWATER FROM INDIVIDUAL UNIT OPERATIONS

Fill out a separate form for each unit operation

UO-_____ **Process #_____** **Site terminology for unit operation:** ____________________________

POC: ____________________________________ **Phone:** ____________________________________

Base material(s): ____

Applied/removed material(s): ____

Annual production rate (units): _________________________________

Operating schedule: __________ hrs/day __________ days/yr

Annual process wastewater discharge (not including rinse water): ___________________ gal/yr

List the chemical or trade names of all additives:

_________________________________ _________________________________

_________________________________ _________________________________

What are your criteria for discharging wastewater?

❑ As it is used
❑ Other (e.g., bath conductivity level, contaminant concentration, etc.)

____

____

Do you have lab analysis data on the composition of wastewater from this unit operation?

❑ Yes (Please provide copies)
❑ No

Destination of process wastewater discharge (check all that apply):

❑ On-site treatment
❑ Surface water
❑ POTW
❑ Contract hauled for off-site disposal
❑ Reuse on site
❑ Other: ___________________

Annual rinse water discharge from this unit operation: ___________________ gal/yr ❑ None

❑ Spray ❑ Immersion ❑ Other: ___________________

Do you have lab analysis data on the composition of rinse water from this unit operation?

❑ Yes (Please provide copies)
❑ No

Destination of rinse water discharge (check all that apply):

❑ On-site treatment
❑ Surface water
❑ POTW
❑ Contract hauled for off-site disposal
❑ Reuse on site
❑ Other: ___________________

What are your criteria for discharging rinse water?

❑ As it is used
❑ Other (e.g., bath conductivity level, contaminant concentration, etc.)

____

____

PROCESS WASTEWATER FROM INDIVIDUAL UNIT OPERATIONS (cont.)

Does this unit operation have a water curtain? ❑ Yes ❑ No

What is the annual water curtain wastewater discharge for this unit operation?
____________________ gal/yr

Do you have lab analysis data on the composition of water curtain wastewater discharge?

❑ Yes (Please provide copies) ❑ No

Destination of water curtain wastewater discharge (check all that apply):

❑ On-site treatment
❑ Surface water
❑ POTW
❑ Contract hauled for off-site disposal
❑ Reuse on site
❑ Other: _____________________

Pollution prevention technologies used for this unit operation (check all that apply):

❑ In-process membrane filtration
❑ In-process ion exchange
❑ In-process centrifugal separation
❑ In-process oil skimmer
❑ In-process electrolytic recovery
❑ In-process evaporation
❑ In-process reverse osmosis
❑ Other(s): _____________________

Unit operation flow diagram:

Illustrate water use, treatment, and disposal. Clearly indicate any water reuse or recycle or any continuous use of process water. Assign flow rates (amount and frequency) for all water/wastewater streams.

STORM WATER RUN-OFF

Annual storm water discharge: ____________________ gal/yr

Contributing process areas:

__________________________________ __________________________________

__________________________________ __________________________________

__________________________________ __________________________________

Do you have lab analysis data on the composition of storm water from your facility?

❑ Yes (Please provide copies) ❑ No

Destination of storm water discharge (check all that apply):

❑ On-site treatment
❑ Surface water
❑ POTW
❑ Contract hauled for off-site disposal
❑ Reuse on site
❑ Other(s): ____________________

Storm water run-off flow diagram:
Show all contributing processes and discharge destinations. Assign flow rates (amount and frequency) for all water/wastewater streams.

WASTEWATER TREATMENT SYSTEMS

Does your site operate one or more wastewater treatment systems? ❑ Yes ❑ No
(If yes, fill out a separate page for each treatment system.)

TS #_____

Wastewater flow through unit: _________________________ gal/yr

Do you have lab analysis data on the composition of wastewater from this treatment system?

❑ Yes (Please provide copies) ❑ No

Unit operations discharging to this treatment unit:

UO-_____ UO-_____ UO-_____ UO-_____

UO-_____ UO-_____ UO-_____ UO-_____

Destination of water discharge (check all that apply):

❑ Surface water
❑ POTW
❑ Contract hauled for off-site disposal
❑ Reuse on site
❑ Other(s): ____________________

Wastewater treatment flow diagram:

Show all inputs and outputs. Assign flow rates (amount and frequency) for all water/wastewater streams.

CONTRACT HAULING AND DISPOSAL COSTS

Process Wastewater	Contributing Unit Operations (UO #s)	Amount Removed (gal/yr)	Total Annual Contract Hauling/Disposal Costs ($/yr)
Chromium-bearing wastewater			
Cyanide-bearing wastewater			
Chelated or complex metal-bearing			
Other metal-bearing wastewater			
Oily wastewater			
Painting wastewater			
Paint stripping wastewater			
Other (specify):			
Other (specify):			
Other (specify):			

OTHER WASTEWATER TREATMENT/DISPOSAL COSTS

Wastewater Stream	Contributing Unit Operations (UO #s)	Amount (gal/yr)	Total Annual Treatment/ Disposal Costs ($/yr)

APPENDIX C

Project Wastewater Data

Table 1. Process Wastewater Stream Data

Process	Shipyard	Quantity	Contaminants	Discharge Location
Acid Cleaning	NASSCO	25,250 gal/yr haz	oils, metals, pH	WWTF, rinse only cleaning tank
Alkaline Cleaning for Oil and Grease Removal	NASSCO	25,250 gal/yr haz	oils, metals, pH	WWTF, rinse only cleaning tank
Aqueous Degreasing	Avondale	2,020,192 gal/yr	oils, rainwater	WWTF, POTW
	BIW	4110 gal/yr haz	Pb	hauled
	BIW	3214 gal/yr nonhaz	Pb	hauled
Chemical Milling/Machining	NASSCO	36,400 gal/ yr haz	Ag, pH	WWTF
Chromate Conversion Coating	Avondale	55 gal/job	Cr	hauled
Corrosion Preventive Coating	Avondale	55 gal/job	Cr	hauled
Deballasting	BIW	540,000 gal/yr	oil, residual fuel	WWT/River
Developing, X-ray	BIW	3120 gal/yr	Zn, TSS	WWTF
	NASSCO	6,400 gal/yr		POTW
Heat Treating	Avondale		None - non contact	River
	BIW	10,000 gal/yr	heat	River, WWTF
	NASSCO	12,200 gal/yr	metals	ground evaporation
Insulation and Flooring	Avondale	2585 gal/yr	glue	hauled
Painting	Avondale	2780 gal/yr	organics	
	NASSCO	300,00 gal/yr haz	organics, Zn	Haz. disposal
Pipe Bending	Avondale	48,010 gal/yr		POTW
Pipe Flushing	BIW	65-70,000 gal/yr	Cu, Ni, Pb	hauled
Pipe Flushing and Testing	Avondale	285,000 gal/yr		WWTF
Pipe Hydrotesting	BIW	5,000 gal/yr	none	WWTF
	NASSCO	unknown	metals	WWTF
Plasma Arc Cutting	NASSCO	0 for '98 (8000 gal in tanks)		WWTF (17,000 gal collected due to rain)
Plasma Arc Welding	Avondale			River
Soldering/Brazing	NASSCO	2,600 gal/yr	metals	ground evaporation
Storm Water	Avondale	256,960,000 gal/yr		
	BIW	5,606,208 gal/yr		River
	NASSCO	3,371,810 gal/yr ('98)	Cu, Zn, TPH	WWTF and Bay
Stripping/Hydroblasting	BIW	1,314,000 gal/yr	paint chips	River
	NASSCO	3,709,726 gal/yr	paint chips	WWTF
Thermal Cutting	Avondale		metals	hauled and river
Washing, Bilge	BIW	20,000 gal/yr	oil	WWTF
Washing/Steam Cleaning	NASSCO	16,150 gal/yr	oil, metals	WWTF
Wet Air Pollution Control	BIW	40,000 gal/ discharge, scrubbers	Zn, TSS	Hauled
	BIW	124,800 gal/yr, electrostatic ppt.	Zn, TSS	Sewer
	NASSCO	5,700 gal/yr (1998)	Zn	WWTF

Note: Blank cells indicate that data was not available at this time.

Key: gal = gallon; haz = hazardous waste; nonhaz = nonhazardous waste; POTW = publicly owned treatment works; TPH = total petroleum hydrocarbons; TSS = total suspended solids; WWTF = wastewater treatment facility; yr = year

APPENDIX D

Demonstration Reports

Report Number 3

NSRP Project N1-96-5
Trailer Mounted Water Recovery and Reuse System
NASSCO PO Number MU322646-D

BATH IRON WORKS SHIPYARD WASTEWATER RECOVERY AND REUSE TECHNOLOGY DEMONSTRATION REPORT

Technical Report

NOVEMBER 30, 2000

BY:

CONCURRENT TECHNOLOGIES CORPORATION
100 *CTC* DRIVE
JOHNSTOWN, PA 15904

EXECUTIVE SUMMARY

The following report summarizes a demonstration of recycle / recovery technologies at Bath Iron Works, Bath, Maine, conducted by Concurrent Technologies Corporation (*CTC*) under the National Shipbuilding Research Program (NSRP). The solutions that were tested for recovery include:

- An aqueous degreasing solution for post cleaning of pipe after a bending operation, and
- An acidic solution used to clean primarily copper pipe after a sweating operation.

These solutions pose a disposal problem after depletion. If the level of lead within the solutions exceed 5 ppm, the cost of disposal of these solutions dramatically increases. Membrane electrolysis and ion exchange technologies were demonstrated to reduce/ remove the primary contaminant of these solutions, Lead. The membrane electrolysis technology was unsuccessful at removing lead from the brulin solution. The ion exchange technology demonstrated with a variety of resins should success at the removal of lead from these solutions.

1.0 INTRODUCTION

A demonstration of recovering alkaline cleaners for the pipe bending process plant was conducted at Bath Iron Works (BIW), Bath, ME, during February 28, 2000, through March 3, 2000. The alkaline cleaning solutions of interest were Brulin and Bernite cleaning baths. Currently, the lead content in these tanks can become excessive (above 5ppm) with use and require hazardous waste disposal. It is thought that lead is introduced from the pipes as a contaminant. The tanks are upstream of rinse water tanks, and as such are a point source for drag-out into the rinse water tanks.

2.0 DEMONSTRATION METHODS

Cation exchange beads, and membrane electrolysis technology, were evaluated for the removal of lead from the Bernite and Brulin solutions. The Brulin solution was processed through the cation exchange beads and membrane electrolysis, while the Bernite solution was processed through the cation exchange beads, only[2].

2.1 Cation Exchange Beads

Three cation exchange resins (of varying ionic resin strength and selectivity) were tested for removing the lead contaminant (a cation) from the cleaners:

1. Strong Cation Exchange Resin
2. Weak Cation Exchange Resin
3. Chelating Cation Exchange Resin

Strong cation exchange resins attract any cation, but exhaust quicker than the weak cation exchange resins do. Also, this demonstration at BIW tested chelating resins that are manufactured to selectively attract specific cations such as lead.

The cation exchange resins were also tested for their ability to be regenerated for reuse. For the regeneration, weak hydrochloric acid and a rinse water flush was passed through the cation exchange resin bed. If initial results appeared promising, the regenerated cation exchange resin bed was reused to retest its ability to treat additional alkaline cleaner.

The demonstration measured, calculated, and recorded:

- Removal efficiency of lead in the solutions,
- If the existing chemistry was altered,
- Regeneration efficiency,
- Volume treatable before exhaustion, and
- The requirements of scale-up to BIW operations.

[2] The Bernite cleaner contained a few species that could react in the membrane electrolysis cell to become dangerous compounds that generate off-gas into the operations work areas. As a result, this configuration of membrane electrolysis was not attempted.

2.2 Membrane Electrolysis

Another technology tested to remove lead from the alkaline cleaner was membrane electrolysis. It uses a cation exchange membrane sheet to partition the cell into two compartments, namely a "catholyte" cell and an "anolyte cell. An electrical voltage moves ions from one solution, through the membrane, and then deposits those ions into another solution. In the BIW demonstration, an electrically conductive solution of sodium hydroxide was used in the catholyte cell, and the process solution (Brulin cleaner) in the anolyte cell. In this configuration, the focus of the technology was to pull positive ions (such as lead) across the cation permeable membrane to the catholyte cell for precipitation in the caustic solution.

The lead removal was evaluated at three direct current (DC) electrical voltage levels, considered in this process to be high-, mid-, and low-levels (9, 3 and 2 Volts DC respectively). The solutions were pumped through the cell compartments at equal rates, and the solution temperature was 100°F (38°C).

This technology was selected because it has some desirable attributes for continuous treatment of solutions. The process solution can be treated from the work tank, without alteration, other than cation removal.

3.0 RESULTS

The data presented below report the results of each demonstration at the BIW.

- Calculated resin column to be 0.01 ft^3.
- Recommended flow is approximately 1 gpm / ft^3 of resin. (This equates to a volumetric flowrate of approximately 38 mL/min.)
- Solution temperature was 99°F (37°C)

3.1 Brulin - Cation Exchange Beads

A relatively quick evaluation was conducted on the Brulin solution with the strong cation exchange bed. It stripped active constituents from the Brulin solution, changing its color from the standard clear and blue, to milky. The strong cation exchange bed lowered the pH of the Brulin cleaner to a significantly acidic, unusable condition (see Table 3).

Table 15. Brulin Cleaner Recovery Evaluation Results for Cation Beads

Technology/ Cation Resin	Time (minutes)	Conductivity (mS)		pH (S.U.)		Lead (mg/L)	
		In	Out	In	Out	In	Out
Strong	12.5	9.5	9.7	9.65	1.55	1.4	0.10
Weak - unused	35	9.5	10.7	9.65	9.79	1.4	BDL
Weak - used	12.5	9.7	6.4	9.59	6.74	1.5	BDL
Chelating	12.5	9.5	10.0	9.65	10.18	1.4	BDL

BDL - Below Detectable Limit

The unused (new) weak cation exchange beads removed the lead contaminant without altering the Brulin solution (based on pH and conductivity shown in Table 3). Conductivity and pH rose indicating the possibility that the Brulin solution was recovered. However, the volume of hydrochloric acid (4% HCl) and associated rinses required to regenerate these weak cation exchange resin beads approached the volume of Brulin cleaner recovered, which resulted in no significant decrease in waste volume by this overall process. Further, after regeneration, these used weak cation exchange resin beads appear to strip the Brulin cleaning solution of other constituents, based on the solution's lower pH and relatively low conductivity. It appears that, whereas the unused weak cation exchange bed processed the Brulin successfully, the regenerated bed wasn't successful.

The chelating ion exchange beads seemed to recover the Brulin cleaner, based on the higher pH and conductivity on the discharge compared to the contaminated Brulin cleaner feed. Although it appeared to strip the blue colored dye from the Brulin solution, this does not affect the cleaner performance. The conductivity and pH of the processed solution seemed improved, and the lead was removed.

3.2 Bernite - Cation Exchange Beads

The strong cation appeared to work well on the Bernite solution, but a check on the pH of virgin Bernite solution is required. The pH of the processed solution was somewhat lower than the feed solution. This could be the result of successful removal of metal (lead) and regeneration of the Bernite solution. Regeneration of the bed was successful.

The chelating resin beads removed lead from the Bernite solution, as can be seen in Table 4. However, the pH of the processed Bernite indicates that it lost its useful acidity, and therefore, based on an acceptable pH criteria, it would not be an effective cleaner for reuse.

Table 16. Bernite Cleaner Recovery Evaluation Results Summary

Technology/ Cation Resin	Time (minutes)	Conductivity (mS)		pH (S.U.)		Lead (mg/L)	
		In	Out	In	Out	In	Out
Strong	25	92.0	106.2	3.03	1.77	5.5	BDL
Chelating	50	92.0	72.8	3.03	6.01	5.5	BDL

3.3 Membrane Electrolysis: Brulin

The membrane electrolysis technology was unsuccessful in the removal of lead from the Brulin solution. Some data for the mid and low-voltage runs seemed to show a small reduction in the lead content. Further investigation is warranted.

Table 17. Brulin Cleaner Recovery Evaluation Results for Membrane Electrolysis

Technology/ Membrane Elec.	Time (minutes)	Conductivity (mS)		pH (S.U.)		Lead (mg/L)	
		In	Out	In	Out	In	Out
7 Volts DC	60	11.2	10.0	9.59	9.04	1.4	1.5
3 Volts DC	180	11.0	7.9	9.63	9.31	1.3	0.9
2 Volts DC	120	9.7	11.0	9.59	9.60	1.5	1.1

4.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, the weak cation ion exchange removed lead from the Brulin solution, but the efficiency and quality of the regeneration needs to be investigated. Economical regeneration of the weak cation resin beads, after processing the Brulin cleaner solution, may not be possible. The strong cation ion exchange bed regenerated the Bernite solution, but the pH of the processed Bernite solution needs to be verified if it is acceptable.

The membrane electrolysis appeared not to sufficiently remove lead from the Brulin. A switch in the electrolytic cell may be more efficient. In this configuration, the catholyte cell would contain Brulin and the anolyte cell, the caustic solution. In this configuration, the lead would basically be plated out on the cathode, therefore reducing the lead content of the process tank.

Report Number 4

NSRP Project N1-96-5
Trailer Mounted Water Recovery and Reuse System
NASSCO PO Number MU322646-D

AVONDALE SHIPYARD WASTEWATER RECOVERY AND REUSE TECHNOLOGY DEMOSNTRATION REPORT

Technical Report

NOVEMBER 30, 2000

BY:

CONCURRENT TECHNOLOGIES CORPORATION
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JOHNSTOWN, PA 15904

EXECUTIVE SUMMARY

The following report summarizes a demonstration of recycle / recovery technologies at Avondale, New Orleans, Louisiana conducted by Concurrent Technologies Corporation (*CTC*) under the National Shipbuilding Research Program (NSRP). The solutions that were tested for recovery include:

- An acidic compressor flushing solution, and
- An acidic pipe flushing solution.

The solutions are used to de-scale piping. After usage, they are titrated to a nominal pH (~7) at which point the metals are then precipitated. This report summarizes the successful demonstration of microfiltration technology to reduce the volume of precipitated laden solution.

1.0 INTRODUCTION

A demonstration of microfiltration technology was conducted at Avondale Shipyard in New Orleans, LA, on waste streams created from the flushing of compressors and piping. A solution of hydrochloric acid is used to flush compressors and pipe primarily for de-scaling. The waste solution is titrated to nominal pH (pH ~7) at which point the metals precipitate out of solution and are disposed of properly.

1.1 Demonstration Methods

Microfiltration technology is ideal in the removal of particulate material in solution, in comparison to conventional filtration. Microfiltration technology allows the continuous regeneration of the membrane surface through back flushing, whereas conventional filter systems need continually changed when loaded. Both pipe and compressor flushing solutions were processed by the microfiltration.

The microfiltration system demonstrated, utilized a 0.8 µm ceramic membrane. Ceramic membranes do not degrade at temperatures above 90 deg F and pH extremes, as exhibited by polymeric membranes. The system has a capacity of 2 - 5 gpm depending on effluent quality.

2.0 RESULTS

The microfiltration system performed overall, very well. Although the loading in the system due to the concentration of precipitates seemed high, the microfiltration permeate capacity did not diminish. Table 6 contains the raw sample data for the demonstration. The concentrate data represents the rejected material while the permeate data represents the cleaned material. Since the microfiltration technology can only remove particulate, reductions in metals and total suspended solids (TSS) represent the removal of those materials that were insoluble.

Table 18. Results Summary for Pipe and Compressor Flush Recovery Evaluation

Parameter (mg/L)	Detection Limit (mg/L)	Pipe Flush		Compressor Flush	
		Microfilter Concentrate	Microfilter Permeate	Microfilter Concentrate	Microfilter Permeate
TSS	2.0	460	350	3,570	535
TDS	2.0	8,116	45,550	103,840	103,730
Cadmium	0.01	BDL	BDL	0.12	BDL
Chromium	0.01	1.01	0.45	1.24	0.14
Copper	0.01	26	15	260	54
Lead	0.05	BDL	BDL	1.09	BDL
Nickel	0.02	1.40	1.23	1.79	1.36
Zinc	0.01	30	160	640	360
Silver	0.01	BDL	BDL	BDL	BDL
Mercury	0.002	BDL	BDL	BDL	BDL

[1]mg/L = milligrams per liter = parts per million (PPM)
[2]TSS = Total Suspended Solids
[3]TDS = Total Dissolved Solids
[4]BDL = Below Detection Limit

2.1 Compressor Flush

As can be seen from Table 1, the specific metal content was reduced along with the TSS. Visually, the permeate was clear, representing also, particulate were removed. The specific metal content could be further reduced by titrating the acidic flushing solution to the inflection point that the metal is at its most insoluble point.

The permeate flowrate maintained its capacity throughout the processing of over 150 gallons. Due to the relatively heavy TSS loading observed, if a microfiltration system was sought, one should consider implementing a filter press to operate off the microfiltration work tank. This would reduce microfiltration loading and further reduce the volume of waste to be disposed.

2.2 Pipe Flush

In general, the results of the pipe flush demonstration mimic those of the compressor flush demonstration. It is evident when looking at the zinc component data that something went amiss. The pipe flush demonstration was conducted after the compressor flush demonstration, and the rise in this data could be attributed to cross-contamination. The system should have been fully decontaminated before the second demonstration was conducted.

As seen in the compressor flush demonstration, the permeate flowrate did not diminish throughout the duration of the demonstration. The permeate solution appeared clear.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Both demonstrations can be considered a technical success. If the effluent can be deemed non-hazardous and fit within the realm of disposal limits at Avondale, the overall volume of waste disposal can be reduced. An integrated system with a titrator and microfiltration would be ideal. In addition, a filter press or some other technique can be employed to deal with the slurry of metals.

Report Number 5

NSRP Project N1-96-5
Trailer Mounted Water Recovery and Reuse System
NASSCO PO Number MU322646-D

NATIONAL STEEL AND SHIPBUILDING COMPANY (NASSCO) SHIPYARD WASTEWATER RECOVERY AND REUSE TECHNOLOGY DEMONSTRATION REPORT

Technical Report

NOVEMBER 30, 2000

BY:

CONCURRENT TECHNOLOGIES CORPORATION
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JOHNSTOWN, PA 15904

EXECUTIVE SUMMARY

The following report summarizes a demonstration of recycle / recovery technologies at NASSCO, San Diego, CA conducted by Concurrent Technologies Corporation (*CTC*) under the National Shipbuilding Research Program (NSRP). The solutions that were tested for recovery include:

- A steam cleaning area wastewater, and
- A rinsewater in a caustic pipe cleaning area.

The steam cleaning area at NASSCO provides the cleaning of a large variety of parts and vehicles and as such, the contaminants are of a wide variety. The majority of the contaminants include grease, grime, and dirt. The microfiltration system was employed in this demonstration to reduce the volume of waste that needs to be disposed. During the demonstration, the microfiltration membrane was blinded halting the demonstration.

The rinsewater application was from a caustic pipe cleaning area where copper pipes that have been sweated are dipped in a caustic bath and then subsequently in a rinsewater bath. This rinse water will contain metal hydroxide particulates that deplete the rinsing action of the water. The microfiltration technology was employed in this application to maintain the rinse quality of the water, by removing these metal hydroxides on a continual basis. The results of this demonstration verify that there would be a technical advantage to using this technology for maintaining rinsewater quality for this application.

1.0 INTRODUCTION

The following report summarizes a demonstration of recycle / recovery technologies at NASSCO, San Diego, CA conducted by Concurrent Technologies Corporation (*CTC*) under the National Shipbuilding Research Program (NSRP). The solutions that were tested for recovery include:

- A steam cleaning area wastewater, and
- A rinsewater in a caustic pipe cleaning area.

The steam cleaning area at NASSCO provides the cleaning of a large variety of parts and vehicles and as such, the contaminants are of a wide variety. The majority of the contaminants include grease, grime, and dirt. The microfiltration system was employed in this demonstration to reduce the volume of waste that needs to be disposed.

The rinsewater application was from a caustic pipe cleaning area where copper pipes that have been sweated are dipped in a caustic bath and then subsequently in a rinsewater bath. This rinse water will contain metal hydroxide particulates that deplete the rinsing action of the water. The microfiltration technology was employed in this application with some success to maintain the rinse quality of the water, by removing these metal hydroxides on a continual basis.

2.0 DEMONSTRATION METHODS

This section provides information onto the rational of the demonstration. The issues surrounding each solution process are addressed, and how the technology was applied.

2.1 Steam Cleaning

The microfiltration technology was used for the demonstration of wastewater recovery at NASSCO. The steam cleaning area near the maintenance department is used to clean a variety of items that can be found around the shipyard. As such the contaminants are diverse. The microfiltration was used in this application to handle the grease and oils, while reducing suspended solids. The original intention of the demonstration was to use both microfiltration and reverse osmosis technology to clean the waste solution sufficiently enough to be reused in the steam cleaning process.

2.2 Pipe Rinse

The microfiltration technology was also demonstrated on a rinse tank in a caustic pipe cleaning area. Primarily, sweated and constructed copper pipe is cleaned with a caustic solution, then dipped in a rinse water bath. The focus of the demonstration on this solution was to increase the quality of the rinse water through the removal of metal hydroxides that may exist, thereby extending the life of the rinse bath and reducing the volume of waste generated by the operation. Caustic rinse baths are plagued by precipitate material comprised of metal hydroxides that are dragged out from the primary caustic bath into the rinse bath. A properly sized microfiltration system can remove these particulate contaminants, thereby extending its bath life and reducing the subsequent volume reduced in a period of time. Primarily, rinsing baths need to be of low conductivity to be good rinsers. Caustic drag out due to work-piece throughput, will eventual cause the rinse bath to be inadequate for rinsing action.

3.0 RESULTS

The data captured from the two demonstrations at NASSCO can be found in Table 1.

Table 19. Results Summary of Pipe and Steam Rinse Microfiltration Demonstration

Parameter (mg/L)	Detection Limit (mg/L)	Steam Tank		Pipe Rinse	
		Microfilter Concentrate	Microfilter Permeate	Microfilter Concentrate	Microfilter Permeate
Oil & Grease	5	776	9	-	-
TSS	5	134	<5	30	<5
Lead	0.09	-	-	5.03	<0.09
Copper	0.02	-	-	2.84	1.36

3.1 Steam Tank

From the Steam Tank data, it is evident that the microfiltration technology successfully removed oils and grease, and reduced total suspended solids in the waste solution. The permeate was visibly clear, but its flowrate was severely slow, indicating the membrane was blinded. It is assumed that some of the grease components or heavy / large material of the waste solution blinded the membrane surface, resulting in a permeate flowrate around 1 gallon per hour and the back-pulsing steps were unsuccessful. The system usually can provide a 2 to 5 gpm permeate flowrate.

A subsequent demonstration with the permeate from the microfiltration through reverse osmosis technology was planned. Due to the severely slow permeate flowrate seen, the demonstration was shelved.

3.2 Pipe Rinse

Significant reductions in copper and lead levels were observed in the demonstration of the microfiltration technology on the pipe rinse solution. Due to the caustic nature of the upstream bath, the pipe rinse bath also exhibits a relatively high pH. The metals in this solution may exist as particulate that the microfiltration system was able to remove, and consequently clean the bath.

4.0 CONCLUSION AND RECOMMENDATION

In regard with the Steam Cleaning demonstration, successful parameters must first be realized for the microfiltration technology before subsequent work in close-looping the solution can be completed, if desired. It is recommended a lot screen be installed to keep large chunks of material from the microfiltration membrane, and a larger pored membrane replace the existing membrane. Owing that the cost of water is sometimes insignificant in comparison to most items, although it is a natural resource, primary economics are gained from the reduction in the total volume of waste solution that is required for disposal. Typically, wastewater volumes can be reduced by 80 to 90%.

The Pipe Rinse microfiltration demonstration was a success in regard to the removal of metal hydroxides. A relatively small microfiltration system can be integrated with the rinse bath to provide bath extension and bath rinsing quality. The metals will concentrate in the work tank of a proposed microfiltration system and disposed of properly with significantly reduced volume. Through continually cleaning the rinse bath, the frequency of bath dumps per annum can be reduced, therefore reducing the volume of waste disposed of.

APPENDIX E

Cost Analyses

Wastewater Recovery and Reuse Cost Analysis Summary

Description	Scenario	Capital Costs	Annual Costs	Annual Savings	P/B	NPV-15 [1]	IRR
Pipe Bending - Alkaline Cleaner: Ion Exchange	Baseline	NA	$32,400	NA	NA	NA	NA
	Alternative	$10,000	$31,500	$850	14.9 years	$600	4.5%
Compressor Flush: Microfiltration and Ion Exchange	Baseline	NA	$4,500	NA	NA	NA	NA
	Alternative	$14,000	$3,550	$950	NA	($700)	3.5%
Pipe Flush: Microfiltration	Baseline	NA	$285,000	NA	NA	NA	NA
	Alternative	$36,000	$74,650	$210,350	0.34 years	$1,200,000	304.7%
Steam Cleaning: Microfiltration	Baseline	NA	$93,600	NA	NA	NA	NA
	Alternative	$36,000	$27,500	$66,250	1.09 years	$367,500	$95.8%

Notes:
P/B = Simple Payback Period in years (a lower value is generally preferred)
NPV-15 = Net Present Value of costs incurred after 15 years
[1] Calculations based on real interest rate of 4.0% per OMB Circular A-94 [dated June 24, 1999; revised January 2000] to account for the time value of money and a aggregate tax rate of 48% was used.
Straight-line depreciation for a period of 15 years used for all calculations.
NA = Not Applicable

Pipe Bending - Alkaline Cleaner: Ion Exchange

Assumptions that apply to both the Baseline and Alternative Processes:

- The workload used to make these estimates will be the same over the period of the cost analysis.
- Data reflects a 15-year life cycle cost analysis.
- Operating labor will remain consistent.
- Labor costs include operation and maintenance of ion exchange equipment.
- Disposal costs based on cleaner usage of 3,400 gallon per year and $1.02 treatment costs.
- Assumed a 1.5 increase of bath life with implementation of equipment; material costs are $8.50 per gallon.
- Equipment maintenance includes regeneration occurring six times per year.
- Labor rate of $36 per hour used.

Category	**Value**
	Annual Cost Benefit
Direct labor	($6,050)
Materials	$6,000
Waste Management	$900
Net annual cost benefit	**$850**
	Financial Indicators
Initial investment (Year 0)	$10,000
NPV, 15 year	$590
IRR, 15 year	**4.5%**
Payback	14.90 years

Compressor Flush: Microfiltration and Ion Exchange

Assumptions that apply to both the Baseline and Alternative Processes:

- The workload used to make these estimates will be the same over the period of the cost analysis.
- Data reflects a 15-year life cycle cost analysis.
- Operating labor will remain consistent.
- Labor costs include operation and maintenance of microfiltration and ion exchange equipment.
- Waste management costs based on 4,500 gallons per year and $1.00 per gallon treatment costs.
- Estimated water usage due to implementation of equipment is 80%.

Category	**Value**
	Annual Cost Benefit
Direct labor	($1,650)
Materials	($1,000)
Waste Management	$3,600
Net annual cost benefit	$950
	Financial Indicators
Initial investment (Year 0)	$14,000
NPV, 15 year	($700)
IRR, 15 year	3.5%
Payback	NA

Pipe Flush: Microfiltration

Assumptions that apply to both the Baseline and Alternative Processes:

- The workload used to make these estimates will be the same over the period of the cost analysis.
- Data reflects a 15-year life cycle cost analysis.
- This item has a useful life of approximately 10 years.
- Operating labor will remain consistent.
- Labor costs include operation and maintenance of microfiltration equipment.
- Waste management costs based on water usage of 285,000 gallons per year and $1.00 per gallon treatment costs.
- Expected water usage is 80% with implementation of equipment.

Category	**Value**
	Annual Cost Benefit
Direct labor	($16,650)
Materials	($1,000)
Waste Management	$228,000
Net annual cost benefit	**$210,350**
	Financial Indicators
Initial investment (Year 0)	$36,000
NPV, 15 year	$1,200,000
IRR, 15 year	304.7%
Payback	0.34 years

Steam Cleaning: Microfiltration

Assumptions that apply to both the Baseline and Alternative Processes:

- The workload used to make these estimates will be the same over the period of the cost analysis.
- Data reflects a 15-year life cycle cost analysis.
- Operating labor will remain consistent.
- Disposal costs based on water usage of 624,000 gallons per year and treatment costs of $0.15 per gallon.
- Expected savings based on 80% reduction in water usage with implementation of microfiltration equipment.
- Labor costs include operation and maintenance of microfiltration equipment.
- Labor rate of $46 per hours used.

Category	**Value**
	Annual Cost Benefit
Direct labor	($7,750)
Materials	($1,000)
Waste Management	$75,000
Net annual cost benefit	**$66,250**
	Financial Indicators
Initial investment (Year 0)	$36,000
NPV, 15 year	$367,500
IRR, 15 year	95.8%
Payback	1.09 years

APPENDIX F

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